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Report No. CG-D-7-79

LEVEL II

DEEPWATER PORTS APPROACH/EXIT CONTROL CAPABILITIES ASSESSMENT

TECHNOLOGY/SERVICE ALTERNATIVES

Planning Research Corporation
Systems Services Company
7600 Old Springhouse Road
McLean, VA 22102

DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

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16. Abstract

This report presents the results of a part of the Deepwater Ports Approach/Exit Control Capabilities Assessment Study. The report addresses existing or planned capabilities in such areas as traffic separation schemes, communication procedures; surveillance procedures; vessel control/advisory procedures; personnel manning qualifications and training. Pollution control measures and other areas capable of countering the hazards specified in the companion study, entitled Deepwater Ports Approach/Exit Hazard and Risk Assessment, were also included. Control capabilities are grouped into four major categories: ship control measures; pollution control measures; personnel considerations; and others. Various measures, whether existing, planned or potential alternatives, are discussed in detail with respect to system definition, system description, capability, accuracy where applicable, advantages, disadvantages, estimated cost where available, mitigative potential and pertinent references. A discussion on technology/service alternatives is presented in the final section.

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PREFACE

The purpose of this study is to examine the planned and existing hardware, software, and personnel applications which are capable of countering the hazards to deepwater port navigation specified in the companion study, Deepwater Ports/Approach/Exit Hazard and Risk Assessment.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

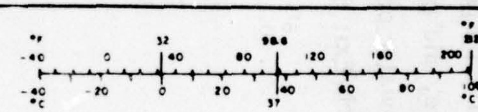


TABLE OF CONTENTS

Page

LIST OF FIGURES

1. EXECUTIVE SUMMARY

The objective of the study, Deepwater Ports Approach/Exit Control Capabilities Assessment, is to determine whether the Deepwater Ports will involve safe navigation operations, and whether the hardware, software and personnel applications planned are capable of countering the hazards specified in the companion study, Deepwater Ports Approach/Exit-Hazard and Risk Assessment.

This report presents the results of a part of the Deepwater Ports Approach/ Exit - Control Capabilities Assessment Study entitled Deepwater Ports Approach/ Exit - Technology/Service Alternatives which was conducted in order to compile explicit descriptions of the navigation technologies and services being planned for deepwater port applications and those significant alternatives available. This task addressed existing or planned capabilities in such areas as traffic separation schemes; communication procedures; surveillance procedures; vessel control/advisory procedures; personnel manning qualifications and training; however, other areas judged to have a potential to counter deepwater port hazards were also included.

Each of the technologies and services was examined to determine its potential to mitigate the hazards which might be encountered in the approach to, and exit from, a deepwater port. Although the focus of this study is the Gulf of Mexico, care has been taken to present the data so as to be applicable to other areas where deepwater ports might exist in the future.

The survey presented in this report has resulted from an extensive literature search, comprehensive interviews with knowledgeable members of the U.S. Coast Guard and the marine industry, and visits by PRC staff members to such activities as the existing deepwater port at Ras Tanura, Saudi Arabia, the Computer Aided Operations Research Facility (CAORF) at Kings Point, New York, the Marine Institute of Technology and Graduate Studies (MITAGS) at Baltimore, Maryland, Marine Safety International at New York City, New York, and Eclectech Associates at North Stonington, Connecticut. In addition, two PRC staff members embarked on a tanker for a transit from Baltimore through the Straits of Florida and the Gulf of Mexico to observe tanker operations in situ.

As a means of providing ready reference to the results herein, the data has been organized into the following categories.

a. Ship Control Measures, including all aspects of navigational aids, weather aids, maneuvering aids and vessel control/advisory procedures.

b. Pollution Control Measures, including cargo separation and monitoring and ship construction techniques (i.e., double bottoms, compartmentation).

c. Personnel Considerations, including manning, training and qualification standards.

d. Other.

Each of the existing or planned mitigating measures is discussed in detail from the aspects of system definition, system description, capability, accuracy (where applicable), advantages, disadvantages, mitigative potential estimated cost (where available) and pertinent references.

The final section of this report summarizes the data surveyed in terms of Technology/Service Alternatives.

The data compiled during this part of the study will provide material for the Deepwater Ports Approach/Exit Control Capabilities Assessment Study, to conduct systems analysis studies to compare the technical and economic feasibility of major mitigating measures and their potential effectiveness in countering key specific hazards which were defined in the companion study, Deepwater Ports Approach/Exit-Hazard and Risk Assessment.

II. INTRODUCTION

A. Background

To demonstrate that the Deepwater Ports will involve safe navigation operations, it must be shown that the hardware, software, and personnel applications planned are capable of countering the hazards specified in the companion study, Deepwater Ports Approach/Exit - Hazard and Risk Assessment. For this reason, this study on technology/service alternatives has been conducted concurrently with the study on hazard and risk assessments to compile descriptions of navigation technologies and services available or planned for deepwater port operations together with other systems now in existence or which may be reasonably available in the near future. This compilation covers: ship control; pollution control; personnel manning qualifications and training; and other mitigating measures.

In this report, explicit descriptions are given in summarized form of planned and alternative technologies and services which have an actual or potential mitigating effect on the hazards of Deepwater Port operations identified in the report on hazard and risk assessment. The information developed in this report will help provide some of the material for subsequent systems analysis in the Deepwater Ports Approach/Exit - Systems Analysis Study to compare the technical and economic feasibility of major mitigative measures and their effectiveness in reducing specific important hazards identified in the study on hazard and risk assessment.

B. Purpose and Scope

In developing the mitigative measures information in this report, a systematic search has been made of literature, knowledgeable persons have been consulted, and visits have been made to organizations known to be engaged in some aspect of vessel operations research. A heavy emphasis has been placed on systems and technologies which currently exist and whose effectiveness has been demonstrated by widespread use over extended periods of time. Examples of these are: Loran-C, Decca, and Collision Avoidance Systems. At the same time, systems which are newly operational or planned for operation have also been included. Examples of these are: Omega, vessel traffic control, and crude oil tank washing. And, finally, systems which offer future promise as mitigative measures, have been examined. Examples are: Global Positioning System and the Eclectech Radar Predictor.

Based on this detailed examination of mitigative measures, a number of systems will be selected for further study which have a high theoretical potential for reducing the deepwater port operational hazards previously identified in the study on hazard and risk assessment. Systems analysis, simulation and cost benefit techniques will be utilized in determining those areas which offer maximum ameliorative effect at the least possible cost.

III. SURVEY CATEGORIES

A. Ship Control

1. Navigational Aids

a. Electronic Navigational Aids

- Loran-C
- Decca
- Omega and Differential Omega
- Radar
- Collision Avoidance Radar Systems
- Radar Piloting Predictor
- Consol
- Consolan
- NAVSAT
- NAVSTAR
- Ships' Inertial Navigation System (SINS)
- Doppler Navigation System
- Fathometer and Sonar
- Navigation Data Assimilation Computer (NAVDAC)
- Miniature Inertial Navigation Digital Automatic Computer (MINDAC)
- Radio Direction Finding (RDF)
- Bridge-to-Bridge Radiotelephone
- Radio Sextant
- Ship/Shore Radio Communications
- Radar Beacons (RACON), Radar Markers (RAMARK)
- Marine Information Broadcasts
- Technical Services Broadcast by the National Bureau of Standards

LORAN-C

System Definition

Loran-C is a *long range, hyperbolic, low frequency, multipulsed, cycle* matching, free running, radionavigational aid. All Loran-C transmitters operate at a fixed frequency of 100 kHz and confine 99% of their radiated energy within the 90 to 110 kHz band. The name Loran is derived from "long range navigation."

System Description

The general principle upon which Loran systems determine position is as follows:

The Loran system measures the difference in times of arrival of pulses from widely spaced synchronized transmitting stations. Because electromagnetic waves *travel with the speed of light* appropos to the medium through which the wave travels, a line of position represents a constant range difference from the two transmitters and is a hyperbola.

A Loran chain is made up of a master transmitting station and two or more secondary stations. The master transmits a pulse signal at time $t = 0$, and the secondary transmits a similar pulse signal σ microseconds after receiving the master pulse signal. The secondary station receives the master signal at time $t = \alpha$ microseconds and therefore transmits its pulse at time $t = \sigma+\alpha$ microseconds. A receiver on board ship measuring the difference in the times of arrival of the signals from the secondary and master stations measures the time difference $TD = (\sigma+\alpha) + t_{secondary} - t_{master}$. The locus of all points with a constant time difference is a hyperbola on one of whose points the receiving ship lies. The hyperbola determined by the same master with an *additional secondary is sufficient to fix the* ship's position which lies at the intersection of the two hyperbolae. The transmitting stations of a Loran-C chain transmit groups of pulses at a specific Group Repetition Interval (GRI). Each pulse has a 100 kHz carrier. The shape is such that 99 percent of the radiated energy is contained between the frequencies of 90 and 110 kHz. For each chain a minimum GRI is selected of sufficient length so that it contains time for transmission of the pulse group from each station (10,000 microseconds for the *master and 8,000 microseconds for each secondary) plus time* between each pulse group so that signals from two or more stations cannot overlap in time anywhere in

the coverage area. Thus, with respect to the time of arrival of the master, a secondary will delay its own transmissions for a specified time, called the secondary coding delay or σ. The minimum GRI is therefore a direct function of the number of stations and the distance between them. A GRI for the chain is then selected so that adjacent chains do not cause mutual (cross-rate) interference. The GRI is defined to begin coincident with the start of the first pulse of the master group.

Each station transmits one pulse group per GRI. The master pulse group consists of eight pulses spaced 1,000 microseconds apart, and a ninth pulse 2,000 microseconds after the eighth. Secondary pulse groups contain eight pulses spaced 1,000 microseconds apart. Multiple pulses are used so that more signal energy is available at the receiver, improving significantly the signal-to-noise ratio without having to increase the peak transmitted power capability of the transmitters. The master's ninth pulse is used for visual identification of the master, and in a blinking mode, used to warn users that there is an error in the transmissions of a particular station. It is accomplished by turning the ninth pulse on and off in a specified code. The secondary station of the unusable pair also blinks by turning its first two pulses on and off. Most modern receivers automatically detect secondary station blink only, as this is sufficient to trigger alarm indicators.

The normal propagation mode is by means of a groundwave which, because of the relatively low frequency of the carrier, does not suffer from high propagation losses caused by the frequency dependent electrical conductivity tensor giving rise to ohmic losses from the electric field induced currents. The skywave propagation mode can be used, however, with reduced accuracy beyond the area of groundwave reception. It is claimed in Bowditch, page 992, that one hop (off the ionosphere) skywaves can be received at ranges of up to 2,300 nautical miles. Automatic alarms have been incorporated in most receivers to inform the operator when the receiver is tracking on a combined ground wave-sky wave signal.

High accuracy can be gained by measuring the crossover time of individual cycles (10 μs) on the leading edge of the pulse envelope. Since the path of propagation is longer for the sky wave, contamination does not take place until at least 30 μs after the start of the ground wave pulse. Thus, the first three cycles of the signal are stable ground waves. Tracking for position is carried out on the third cycle of each pulse in the pulse group of each station to obtain the maximum precision and stability. By proper electronic signal processing the correct third cycle can be selected and tracked with an alarm available should it be lost.

There are five principal sections of Loran-C automatic acquisition and tracking, cycle matching receivers:

1. Radio frequency sensor.
2. Analog-to-digital converter.
3. Loran clock and timing circuits.
4. Digital processor.
5. Operator controls and displays.

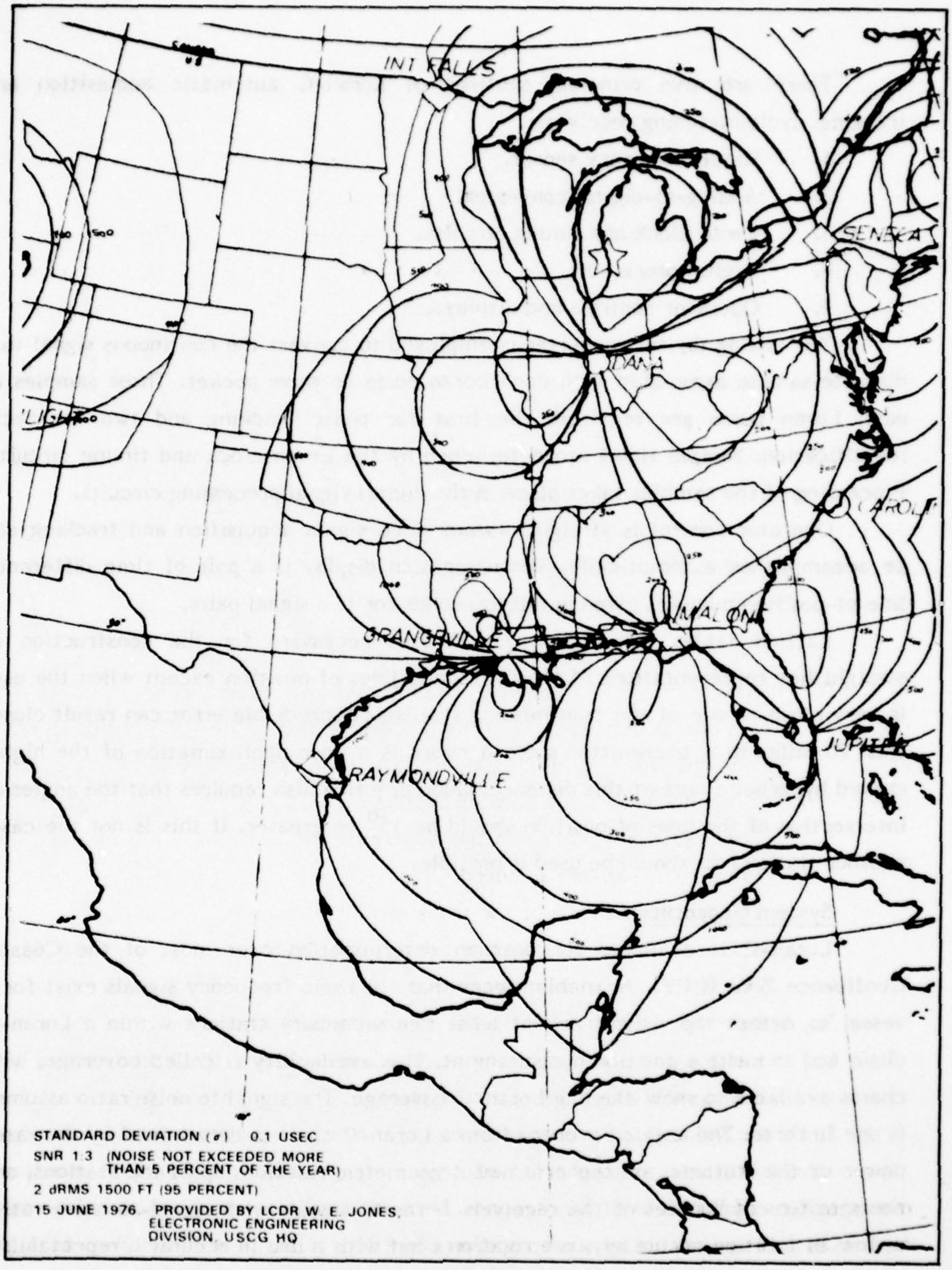
The analog-digital converter is employed to convert the continuous signal to a discrete sample associated with each Loran pulse or wave pocket. Three samples of each Loran pulse are required, the first for phase tracking and two for cycle identification. Sample times are determined by the Loran clock and timing circuits. Processing of the samples takes place in the digital signal processing circuits.

Operator control is straightforward since signal acquisition and tracking can be accomplished automatically. The navigation display is a pair of time difference line-of-position numbers given in microseconds for two signal pairs.

Lattice tables provide the coordinates necessary for the construction of straight line representations of the hyperbolic lines of position except when the user is very close to one of the transmitting stations. Appreciable error can result closer than 20 miles to a transmitter since a chord is a poor approximation of the highly curved hyperbolic arcs at this distance. Good practice also requires that the angles of intersection of the lines of position should be 15° or greater. If this is not the case, another station pair should be used if possible.

System Capability

Loran-C is available for position determination over most of the Coastal Confluence Zone (CCZ). Available means that the radio frequency signals exist for a vessel to detect the master and at least two secondary stations within a Loran-C chain and to make a position measurement. This availability is called coverage, with charts available to show existing Loran-C coverage. The signal to noise ratio assumed is one to three. The usable coverage from a Loran-C chain is determined by the rated power of the stations, atmospheric noise, geometric relationship of the stations, and the specific capabilities of the receiver. Loran-C signals with signal-to-noise ratios as low as 1:10 are usable by some receivers but with a loss in accuracy, repeatability and reliability of the measures. Use of these lower level signals greatly increases the



STANDARD DEVIATION (σ) 0.1 USEC
SNR 1:3 (NOISE NOT EXCEEDED MORE THAN 5 PERCENT OF THE YEAR)
2 dRMS 1500 FT (95 PERCENT)
15 JUNE 1976 PROVIDED BY LCDR W. E. JONES, ELECTRONIC ENGINEERING DIVISION, USCG HQ

FIGURE 1

PROBABLE GEOMETRIC FIX ACCURACY CONTOURS
LORAN-C CHAINS
GULF OF MEXICO
RECONFIGURED EAST COAST

coverage area beyond that shown. Coverage area for the Gulf of Mexico is shown in figure 1.

With the user's receiver appropriately modified to enable time measurements with respect to a local time reference, the Loran-C system can be operated in the ranging or Range-Range (Rho-Rho) mode. The ranging mode or Rho-Rho mode is that method of operation in which the times for the signals to travel from each transmitting station to the receiver are measured rather than their differences. Each time measurement (range measurement) provides a circular line of position.

The feasibility of the ranging mode is dependent upon a stable frequency source, propagation predictability, and a stable time reference within the receiver. The range to a station is calculated from the difference in the known time of transmission and the measured time of arrival of the signal at the receiver. The user's time reference must be initially synchronized to the time standard at the transmitting station. Since perfect synchronization is, in general, not feasible, calibration of the user's time standard is required.

System Accuracy

The accuracy of the fix provided by a hyperbolic radionavigation system, of which Loran-C is one, is dependent upon the accuracy of each line of position used to obtain the fix and the angle of intersection of lines of position. The accuracy of each line of position depends upon the following factors:

1. The precision with which the difference between the times of arrival of two signals can be measured.
2. The synchronization of the transmitting stations.
3. The accuracy of propagation predictions.
4. Operational or receiver accuracy.
5. User's position relative to the transmitting stations.
6. Lattice table and charting accuracies, including the accuracies of the positions of the transmitting stations.

Since the velocity of propagation of radio energy is approximately 1 foot per nanosecond, accuracies on the order of tens of hundreds of feet require measurements to tens of hundreds of nanoseconds. If the time differences are to be converted to lines of position accurately, propagation conditions must be reliably predictable to tens or hundreds of nanoseconds. Receiver accuracy is dependent upon signal-to-noise

ratio, operator skill, and instrumentation. The user's position relative to the transmitting stations governs the spacing between consecutive lines of position per unit time difference, of 1 microsecond. If the spacing is high, a relatively small time-difference error will result in a relatively high position error. Lines are most closely spaced, giving highest accuracy, near the baseline between stations. As the distance between consecutive lines increases, the accuracy decreases, being so low along the baseline extensions that the use of this part of the lattice is normally avoided.

The undesirable divergence of the hyperbolic lines of position varies with the length of the baseline. However, each hyperbola becomes more nearly a straight line (great circle) as distance from the baseline increases. At a distance from the center of the baseline of five times the length of the baseline, the departure of the hyperbola from a great circle becomes very small. Thus, if the baseline is very short, the system can be considered directional beyond a distance of a few miles from the station.

The use of time-difference measurements to establish lines of position serves to minimize the effects on position accuracy of errors caused by propagation anomalies. In a navigation system, predictability is the measure of the accuracy with which the system can define the position in terms of geographical coordinates; repeatability is the measure of the accuracy with which the system permits the user to return to a position as defined only in terms of the coordinates peculiar to that system. Predictable accuracy, therefore, is the accuracy of positioning with respect to geographical coordinates; repeatable accuracy is the accuracy with which the user can return to a position whose coordinates have been measured previously with the same system. For example, the distance specified for the repeatable accuracy of a system such as Loran-C is the distance between two Loran-C positions established using the same stations and time-difference readings.

The terms radial error, root mean square error, and d_{rms} are identical in meaning when applied to two-dimensional errors. Figure 2 illustrates the definition of d_{rms}. It is seen to be the square root of the sum of the square of the 1 sigma error components (σ_1, σ_2) along the major and minor axes of a probability ellipse. The figure details the definition of one d_{rms}. Similarly, other values of d_{rms} can be derived by using the corresponding values of sigma. The measure d_{rms} is not equal to the square root of the sum of the squares of σ_1 and σ_2 that are the basic errors associated with the lines of position of a particular measuring system. It turns out that σ_x and σ_y are related to σ_1 and σ_2 by the formulae:

$$\sigma_x^2 = \frac{1}{2\sin^2\alpha} \left[\sigma_1^2 + \sigma_2^2 + \sqrt{\left(\sigma_1^2 + \sigma_2^2\right)^2 - 4\sigma_1^2\,\sigma_2^2\,\sin^2\alpha}\right]$$

$$\sigma_y^2 = \frac{1}{2\sin^2\alpha} \left[\sigma_1^2 + \sigma_2^2 - \sqrt{\left(\sigma_1^2 + \sigma_2^2\right)^2 - 4\sigma_1^2\,\sigma_2^2\,\sin^2\alpha}\right]$$

where α is the acute angle of cut between the lines of position and σ^1 and σ^2 are the error spreads of lines of position one and two, respectively.

It can be seen that the minimum values of $\sigma_x{}^2$ and $\sigma_y{}^2$ occur for large values of cut angle α.

Since one sigma error corresponds to one d_{rms}, a two sigma error corresponds to 2 d_{rms} and says that, on average, 95.45 percent of the fix readings will fall within the ellipse of figure 2 centered at the given position of the receiver at P. Thus, since σ_1 and σ_2 are a function of position, so is 2 d_{rms}.

The repeatable accuracy of Loran-C, as stated in Bowditch, page 1002, for 1:3 and 1:10 signal to noise ratio is given in terms of 2 d_{rms} and is displayed on the map of figure 3. The 2 d_{rms} error is stated as 1,500 feet or less. The standard deviation of each of the two intersecting lines of position is .1 μs. The repeatability of the system, or the ability to return to a location of a known time delay, is 50 to 300 feet. The usable range of the ground signal is 800 to 1,200 nautical miles; sky waves, however, may be used with reduced accuracy to 3,400 nautical miles.

Differential Loran-C employs a fixed monitor receiver located in the area where more precise position fixing is required. The monitor receives and measures any variation in the signal time differences from the long term average time differences at their particular locations. These variances or deviations are primarily caused by variations in the path propagation time of the signal or variations in the transmitter control timing. The amount of the short term deviation from the long term average deviation is then utilized as a differential correction for the concerned area. The differential correction is transmitted to all ship receivers in the area and the differential correction applied to the ship's time difference readings.

According to the Differential Loran-C time stability studies carried out by R. B. Goddard of International Navigation Corporation,[1] the differential mode attained improvements in performance by a factor of three to six depending on the area. He found that Loran-C in the normal mode consistently provided fix accuracies

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[1] R. B. Goddard. Differential Loran-C Time Stability Study. DOT Report No. CG-D-80-74, November 1973. Bedford, MA: International Navigation Co., 1973.

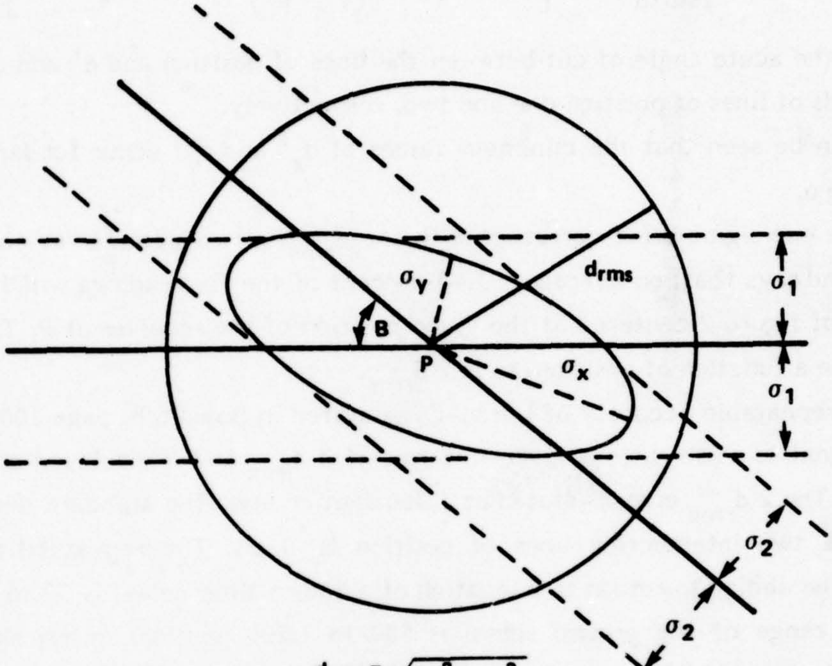

FIGURE 2

DEFINITION OF d_{rms}

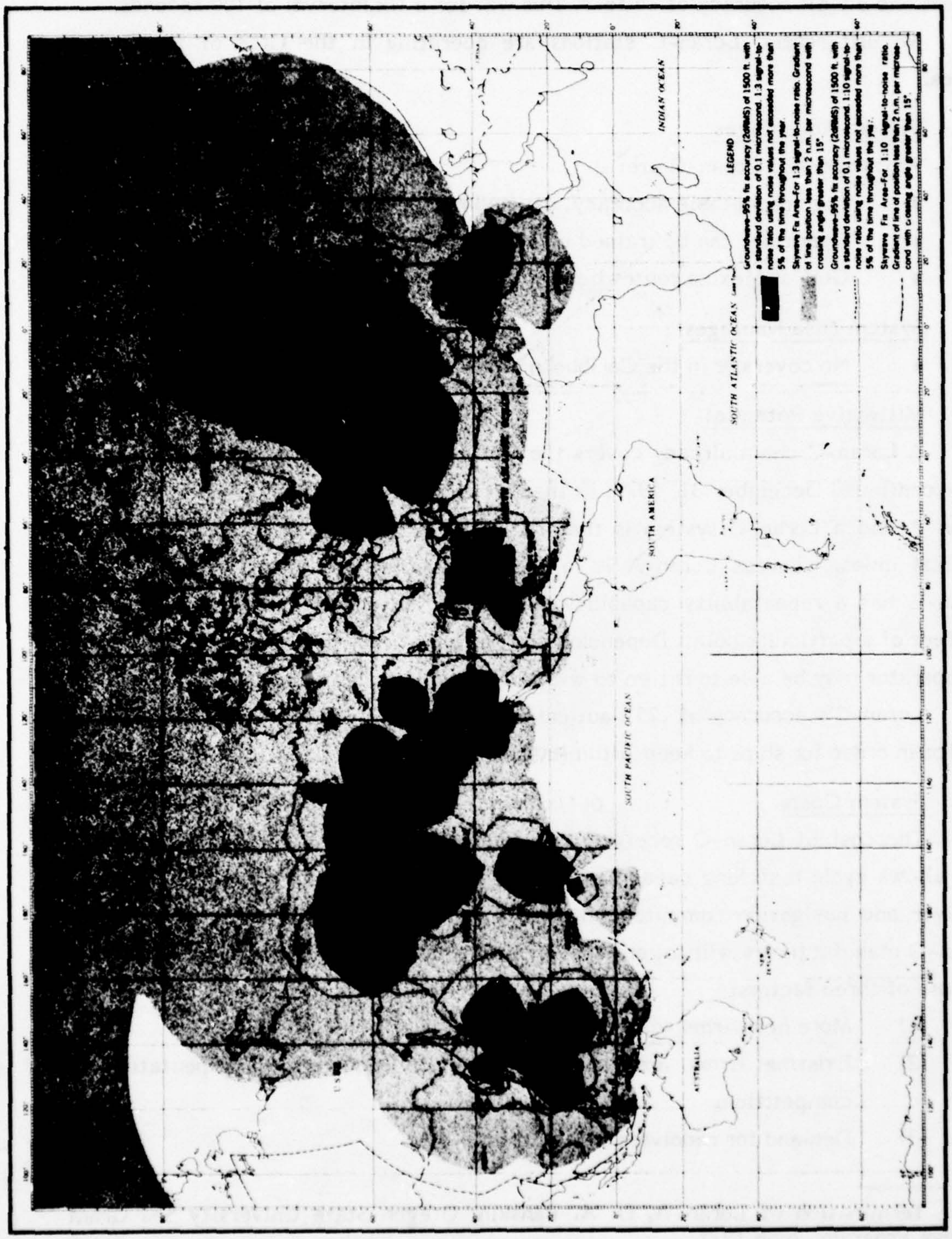

FIGURE 3—LORAN-C COVERAGE DIAGRAM.

of 100 feet, 2 d_{rms} (95 percent) and 38 feet, Circular Error Probability (CEP) (50 percent). When used in the differential mode, he found 2 d_{rms} accuracies of fix of 40 feet and a CEP accuracy of 15 feet. This was for a fix interval of 100 seconds.

No differential Loran-C stations are operating in the CCZ of the United States.

System Advantages

Advantages of Loran-C are:

- High repeatable accuracy, day and night.
- Operators can be trained in a short amount of time.
- Gulf of Mexico routes lie within Loran-C coverage.

System Disadvantages

- No coverage in the Caribbean Sea.

Mitigative Potential

A Loran-C chain already covers the Gulf of Mexico region, while Loran-A will be discontinued December 31, 1979, in that area. The essential difference between a Loran-A and a Loran-C system is that the latter contains a d_{rms} accuracy of .25 nautical miles, whereas Loran-A is in the neighborhood of .5 to 5 miles.[1] Also, Loran-C has a repeatability capability that allows an operator to return to within 300 feet of a particular point. Depending on chain geometry and receiving equipment, the operator may be able to return to within 50 feet of a particular point.

Loran-C's accuracy of .25 nautical miles is sufficient for use in the Gulf of Mexico in order for ships to keep within traffic fairways.

System Costs

The cost of Loran-C receiving equipment on board ship is $2,000 to $6,000. This allows cycle matching capability. A navigation system complete with Loran-C receiver and navigation computer will cost $20,000 to $35,000. It is expected that Loran-C manufacturers will lower receiver prices during the next year or so. This is because of three factors:

(1) More new firms will enter the field.

(2) Existing firms are lowering costs of receivers in expectation of competition.

(3) Demand for receivers will increase.

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[1] Termination of Loran A, D. A. Panskin, Oregon State University Sea Grant College Program, June 1977.

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DECCA

System Definition

Decca is a continuous wave hyperbolic navigation system, which uses phase comparison to determine distance from transmitters. Each chain consists of one master and three slaves. The receiving unit consists of four receivers, one for each frequency. Sponsorship is by the United Kingdom.

System Description

Three colors designate the slave hyperbolas on Decca charts--purple, green, and red. Each of the four stations transmits a continuous wave as a different frequency, the ratios being 5, 6, 8, 9. The signals are in the 70 to 130 kHz band.

Two slaves provide a fix, the third a check or a stand-in for areas where one of the others is not performing well. To determine a position it is necessary to read three dials called decometers and locate the intersection of the two or three lines, indicated on the Decca chart. Since phases are compared between signals of master and slave rather than travel time, no indication of the total number of lines or lanes between them can be obtained. To obtain the necessary information, a lane counter on the receiver equipment is needed.

System Capability

The coverage of a Decca chain is determined primarily by the effects of skywave contamination of the groundwave rather than factors of signal-to-noise ratio or system geometry, and varies with the low frequency propagation conditions characteristic of different regions of the world. Ranges of 175 nautical miles by night and 350 nautical[1] miles by day may be taken as representative when the transmission paths lie over seawater.

The Decca system is continuous, passive and non-saturable. It has a phase locking capability to keep the frequency emitted by the slave station at a constant phase angle relative at the stable frequency receiver from the master station.

Lane identification within a zone is obtained by a process similar to that of determining the fractional value of the lane. As the vessel travels from one zone boundary to another, the lane counter or identification pointer on the receiver makes one revolution against a scale marked in lane numbers.

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1 Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrographic Center, 1977, p. 1012.

The repeatable accuracy to be expected of a Decca fix in a particular coverage area is given in the diagrams in "The Decca Navigator Operating Instructions and Marine Data Sheets" and NP 275(5a), an appendix to volume 5 of the "Admiralty List of Radio Signals." The accuracy is expressed in terms of d_{rms}. The assumed standard deviation of each line of position is 0.02 mean lane. The probability is given at 68 percent. The diagrams in the Decca publication present the repeatable accuracy according to time and season.[1]

System Accuracy

The repeatable accuracy is affected by both random and fixed (systematic) errors. The random errors are largely due to skywave interference with the groundwave, resulting in incorrect Decometer readings. The fixed errors are largely due to errors in propagation prediction. The Decca lattice as overprinted on the navigational chart does not reflect compensation for differences in the conductivities along the actual paths of the signals and the conductivity along an all seawater path. Although the fixed errors are generally small, there are certain regions (e.g., certain coastal waters) where consideration should be given to them when fixing the vessel's positions. "The Decca Navigator Operating Instructions and Marine Data Sheets" include diagrams showing the known corrections which should be applied to the Decca readings. However, it should not be assumed that a fixed error does not exist when a correction is not given. The corrections as given on the diagrams may be too sparse to permit a valid assessment of the correction to apply to the Decometer reading. In such case, not too much reliance should be placed on the absolute or predictable accuracy.

The repeatable accuracy of the system ranges from a few tens of meters by daytime in areas where the geometry is favorable to a few nautical miles in the presence of skywave interference by night at the limit of the range.

System Advantages

Decca System offers the following advantages:

- Good accuracy.
- Easy to use high speed fix system.
- Has been adopted for narrow channel use in Europe.
- Good European coverage.

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1 Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrographic Center, 1977. p. 1012.

System Disadvantages

- Not readily available for Gulf of Mexico use.
- Requires a separate set of receivers and charts.

Mitigative Capability

Interest in extracting the maximum obtainable accuracy from a Decca chain has arisen partly from the problem of navigating, large deep draft vessels through narrow channels in approaches at harbors, such as Europort.

However, due to the lack of United States sponsorship, Decca has no practical mitigative potential for United States waters, since there will be no broadcasting stations near United States waters.

System Costs

Decca receivers are leased.

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OMEGA AND DIFFERENTIAL OMEGA

System Definition

Omega is a VLF (10 to 14 kHz) hyperbolic, continuous wave, position fixing system, using phase difference measurements of continuous wave radio signals. This is a worldwide coverage system since VLF can extend over great distances. Six transmission stations will be required as a minimum with two added stations for redundancy and coverage for an inoperable station.

Developed by the United States Navy and now operated by the Coast Guard, Omega can be used by commercial and private craft. It is not a highly accurate system for near shore navigation, unless a differential Omega system fixed monitor is in use.

System Description

Signals emitted from the eight stations and combined by an Omega receiver aboard ship can provide a stationary radio position field around the world. This radio field is established by transmitting a segment, of approximately one second duration, of a 10.2 kHz carrier from each of the eight stations in sequence. The special Omega receivers have a phase memory capability so that a phase comparison can be made between signals occurring during different time segments. Since the phases of all eight transmission segments are synchronized to a common datum, the phase difference of the signals from any pair of stations provides a stationary pattern of isophase hyperbolic lines of position. The system geometry has been designed so that it should be possible to receive a minimum of four stations at any point in the world, thus a choice of position lines should always be available. This redundancy of position information can be used to improve the accuracy of a fix, or provide a confidence check for the navigator. Radio navigation systems employing phase difference measurements (as distinct from time difference measurements) suffer from the drawback that a particular value of line of position (or iso-phase contour) will be repeated cyclically. The repetition distance, or lane width, of this ambiguity on the base line for hyperbolic systems is one half wave length, which for Omega is approximately 8 nautical miles. If the initial position of the user is not known to an accuracy better than 4 nautical miles, it will be necessary to resolve this uncertainty. The Omega system utilizes transmissions on two additional frequencies (13.6 and 11 1/3 kHz) to effect this resolution. (This process is known as lane identification.) If the phase of the received signals at 13.6 kHz and 11.3 kHz is differenced with the basic

Omega frequency of 10.2 kHz then coarse lanes, respectively 24 nautical miles and 72 nautical miles, are obtained. These coarse lanes can then be used to refine an initial position uncertainty of up to 36 miles down to the point where the basic frequencies of 10.2 kHz can be used.

Omega signals are propagated by skywave mode, and the propagation velocity can be calculated using the concept of signal transmission in the earth-ionosphere waveguide. Due to the daily fluctuations in the height of the ionosphere (the waveguide dimensions), the received phase of the signals will show diurnal variations. This ionospheric movement is sufficiently well understood and predictable to allow the use of precomputed diurnal correction tables in order to achieve the stated system accuracy of the order of two miles.

With respect to Differential Omega, there are certain unpredictable propagation effects which, together with errors in values of diurnal corrections, tend to limit the accuracy of the Omega system. However, due to long correlation distance of VLF transmissions, over a restricted area all users will be subject to similar errors.

This property of the Omega transmissions will enable the accuracy of the system, in a local area, to be enhanced by the use of a fixed monitor station.

This fixed monitor will have known Omega coordinates based on the standard propagation constants. The monitor station will transmit to users the variation of the received Omega signals from the correct coordinates, and these errors will be applied by the user, instead of the pre-computed diurnal corrections, to the readings obtained on board ship. The exact accuracy of such a system will not be determined until measurements can be made using the full power transmitters. The Omega system, besides its main application as an ocean navigational aid, could possibly be used with the differential feature as a medium accuracy coastal aid in locations where coverage from present systems is unsatisfactory, such as near the coast of Cuba.

In using Omega, an operator on board the vessel must be capable of determining the phase of the Omega signals in the presence of the usual ambient noise and interference. The format of the signal permits many different modes of receiver operation ranging from an oscilloscope display of the signal timing, with manual alignment of the multiplexing function, to computer-type receivers capable of performing all functions, and presenting position in the form of geographical coordinates without external aid.

To determine position the operator and receiver must be able to:

- Recognize the total transmitted pattern to identify the transmission of a given set of stations

- Isolate the signal components
- Determine the relative phases of the isolated signal components with accuracy
- Use the phase reading to determine a line of position or a fix

To obtain a line of position when the approximate DR position is known, it is only necessary to read the receiver display, take the Greenwich Mean Time (GMT), and note these data on the work sheet. The appropriate correction table for the general area is then entered, and the diurnal correction for the GMT and date are extracted, and written on the work sheet. This correction is added to the reading taken from the receiver display; the sum provides the required datum for plotting the line of position on the Omega chart. A fix can be obtained in two or three minutes, and it is a simple matter for the operator to obtain an Omega position every hour.

System Capability

Coverage of the system, once operational, will be worldwide and can be put to use by merchant ships provided they have the proper receivers. It will be an all weather system. It also promises to be a highly reliable system.

System Accuracy

The accuracy of an Omega fix is directly related to the accuracy of the propagation correction constants. The published tables are dependent upon the accuracy of predictions, accuracies which increase with continued operation of the system. Monitoring stations accumulate many hours of data which are analyzed by complex analytical procedures to renormalize the predictions which are initially made on theoretical and empirical principles. Only after years of such data collection and analysis (the process is termed "validation,") will it be possible to realize the true worldwide Omega system accuracy of 1 to 2 nautical miles (1.8 - 3.7 km) based on one standard deviation, or 68 percent of positions within the stated limits.[1]

System Advantages

Omega has the following advantages:

- Worldwide all weather coverage.
- Accuracy is not very dependent on distance from transmitters
- Simplicity of operations

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1 Dutton's Navigation and Piloting, 13th Edition, Annapolis, Maryland: Naval Institute Press, 1978. p. 747.

- Reliability through redundancy
- Relatively low cost

System Disadvantages

The Omega System has the following disadvantages:

- Does not identify lane automatically as Loran does. This is a general feature of phase matching
- Is not yet in complete operation
- Reportedly has some propagation difficulties

System Mitigative Potential

The use of Omega receivers incorporating lane identification facilities with two or three frequency receivers could be justified for the navigation of DWP shipping in the approaches to the Gulf of Mexico, especially in the near Caribbean. It is well known that other aids to navigation, especially near Cuba, are unreliable.

Once close to the Straits of Florida, Loran C could take over, which in general has better accuracy, although Omega with a monitor station off Florida could act as a backup in case of Loran failure for a period of time.

Prevention of collision and grounding in the approaches through reduced position uncertainty would be the sought after result. However, it would be difficult to either simulate the effect of Omega or model it analytically. In any case adoption of Omega by ULCC and VLCC carriers is highly probable, because of its wide coverage, ease of use, and reliability.

System Cost

Cost for an Omega System with lane identification capability is $18,000.

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RADAR

System Definition

RADAR is a system of determining distances by measuring the time between transmission and return of electromagnetic signal reflected by the target to the receiver, and bearing by a function of signal bandwidth.

System Description

RADAR has five distinct components:

1. Transmitter -- an oscillator or pulse generator with frequency range of 3,000 to 30,000 MHz.
2. Modulation Generator -- interrupts outgoing signal in such a manner as to create pulses. Range of pulse repetition rate (PRR) is 500 to 3,000 pulses per second.
3. Preamplifier -- amplifies return signal and relays it to the receiver.
4. Antenna -- transmits pulses and receives return signal from target. In general, the familiar rotating parabolic disc.
5. Indicator -- cathode ray tube (CRT) that displays return signal from target for visual reception.

Own ship position is at center of CRT screen. A radial line revolves with the same angular velocity as the radar antenna. Return signals from targets cause small areas of CRT screen to glow. Synchronization of the radial line with antenna plus own ship's course gives true bearing of target. This scheme of presentation is known as Plan Position Indicator, (PPI).

System Capability

Range of radar in the near region is a function of wavelength and sea return but can be as low as 15 yards. Maximum range is essentially determined by line of sight from antenna to earth's horizon. Under certain atmosphere conditions such as temperature inversion, range can extend well beyond line of sight tangency with earth's surface (ducting).

The 3 cm and 10 cm band radar are high resolution systems useful in pilotage; however, they suffer signal weakening during heavy rain and from sea return.

System Accuracy

A typical merchant marine radar has a position fix accuracy determined by two parameters:[1]

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1 Defense Mapping Agency. American Practical Navigator, Bowditch, Volume I. Washington, D.C.: Hydrographic Center, 1977. P. 943.

- Resolution in range -- the ability of a radar to separate targets close together on the same bearing depends chiefly on pulse length. One half the pulse length is the minimum distance that can be measured between objects. Thus, the shorter the pulse, the greater the resolution or accuracy.
- Resolution in bearing -- the ability to separate two targets at same range from own ship depends usually on the beam width, one half the maximum width of the dipole wave form that propagates a meaningful horizontal distance from the antenna. The beam half width occurs at that distance where the field strength is one half of its original strength. For fixed antenna size the beam width is narrowed by decreasing the wave length. For fixed wave length the beam width is narrowed by increasing the antenna size. In terms of range, resolution in bearing improves as range decreases.

The ability to pick up objects very low in the water depends on range, sea height and height of antenna above sea level.

Many factors affect the operational characteristics of radar. The accuracy of positions obtained by radar varies considerably with different types of radar and with the skill of the operator.

Radar can be used in several ways to obtain position. Well determined positions are designated as fixes and less reliable ones as EPs (estimated position), depending on the judgment of the navigator after experience with his equipment.

The accuracy of radar or radar-assisted positions fixes follows in descending order:

Radar ranges and visual bearings on prominent isolated objects;
Radar ranges of several radar-conspicuous objects plotted as position circles;
Radar range and radar bearing of a single charted feature;
Radar bearings of two or more charted features.

System Advantages

- Can be used at night and under low visibility.
- Fix can be obtained from single object, i.e., both range and bearing.
- Fixes are continuous.
- Greater range than visual methods.
- Picks up and tracks large storms.
- Can be coupled with computing and automated equipment to act as a collision avoidance system.

- Has flexibility to be used in different modes to represent different pictures of own ship's position vis-a-vis the outside world. North-up, ship head-up and true motion are examples.

System Disadvantages

- Subject to electro-mechanical failure.
- Near and far field range limitations.
- Interpretation of returns can be difficult, especially when return cannot be correlated to chart information.
- Less accurate than visual plotting.
- Low lying, small objects in water can be masked in high seas and near shore.
- Susceptible to interference from other electromagnetic sources.
- Susceptible to rain and snow interference.

Mitigative Potential

Since all tankers will carry radar of at least the medium resolution variety, we can look forward to the following possibilities with regard to more exotic add-on features or improved resolutions.

1. Stabilized-North Up Radar

True or gyro north is always at 12 o'clock regardless of ship's bearing or course changes. It is claimed by some that this system gives a better feel of the "field" around the ship during maneuvers and will thus reduce probability of collisions. This could be simulated on a designed experimental basis at CAORF, or perhaps MITAGS.

2. Collision Avoidance Schemes

Here relative motion plotting is done automatically, thus relieving the bridge officer of the chore. Accident reduction simulation could be done at CAORF.

3. High Resolution Systems

These could reduce ramming and collisions given that bridge personnel consult them frequently. Simulation of their accident reduction potential could be done on the TSC model, where the parameter perturbed by inclusion of high resolution radar would be own ship's position uncertainty and other ship's position uncertainty. Fixed objects would also be effected in a similar manner. It is interesting to note that the British Navy is contemplating using such radar under conditions of zero visibility.

4. Surveillance Radar

This system can be used in a traffic control mode combined with closed circuit television. In some parts of the world it is already in use. Assessment of its impact by simulation is not yet clear.

5. Radar Charts

Radar charts will show aids to navigation as they would appear on a radar screen and thus reduce confusion between aids and other targets. Assessment of actual mitigating impact would be difficult, since some operators with present equipment and charts are quite good at picking out what they want and others are quite bad at it. A CAORF simulation might give some insight on accident reduction potential of such a chart system.

Costs

The range of cost for a typical commercial radar system spans the interval from $5,000 to $17,000, the latter being the cost of a complete collision avoidance system.

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COLLISION AVOIDANCE RADAR SYSTEMS

System Definition

Collision Avoidance Radar Systems are auxiliary equipments which utilize processed navigational radar data, ship's gyro, and pitometer log inputs to solve relative motion problems associated with contacts which may pose a threat to own ship.

System Description

Collision Avoidance Systems are generally composed of six major components:

1. Video display - a manual Plan Position Indicator (PPI) on which is superimposed alpha numerics, symbols, vectors, circles, etc. In some systems a simulated display is provided which omits sea clutter and substitutes standard images for every contact.

2. Controls - track balls, keyboards, knobs, buttons for manipulating displayed data, or for calling up stored information onto the display.

3. Computer - a general purpose device, with approximately 10k memory, programmed to store track data and to track automatically contacts and generate solutions to relative motion problems in real or projected time.

4. Gyro input - a direct input of ship's true heading from the gyro system, however, fully independent from the gyro system.

5. Pitometer Log input - a direct input of own ship's speed through the water from the pitometer log, however, fully independent from the pitometer log system.

6. Alarms - audio or visual indicators of potential danger to own ship.

System Capability

Range of the system is dependent upon the range of capability of the radar system from which it receives data, while the number of contacts tracked and track life is a function of the installed computer capacity. A typical system can automatically track up to 40 separate contacts within a range of 25 to 30 nautical miles. Tracks of contacts are displayed with course and speed vectors and other symbology in order that the operator can select those of interest. The closest-point-of-approach (CPA) of any contact can be shown. The operator can pre-select a threshold of CPA which will cause the system to actuate an alarm automatically if a

particular contact can be expected to pose a threat to own ship. Many systems allow the operator to initiate a trail maneuver (new course or speed) so as to determine if his solution to avoid the danger is correct; provided, of course, the contact maintains present course and speed. In this case, the system predicts the outcome of a proposed maneuver. Dependent upon the software, the system may indicate the preferred maneuver to the watch officer.

System Accuracy

The accuracy of collision avoidance systems is dependent upon the accuracy of own ship's radar, gyro, and pitometer. Overall, these systems smooth out tracking variations and will provide far greater accuracy than most manual plotting techniques.

System Advantages

- The ability to track automatically and display four times as many contacts as possible using manual methods.
- Tracks are smoothed and catalogued.
- Course and speed changes by contacts are readily identifiable.
- CPA is available continually for all contacts tracked.
- Threats to own ship actuate an alarm promptly.
- The workload on the deck watch officer is reduced significantly providing him with more time to devote to other aspects of vessel safety.
- Provides the watch officer with a rapid means of testing the likely outcome of a contemplated avoidance maneuver.

System Disadvantages

- Possibility of watch officer putting complete reliance on system and neglecting visual clues.
- System accuracy is dependent upon errors inherent in other sensors (radar, gyro, pitometer log).
- Software failure requires reversion to manual plotting with complete loss of continuity for a period of time to reestablish tracks of contacts.
- Constant use may cause watch officers to lose manual plotting ability.

Mitigative Potential

Considered high since all collision avoidance systems relieve watch officers of tedious plotting and maneuvering board relative motion problem solving. The system

offers an opportunity to check maneuvering board solutions before the fact while offering a preferred maneuver from among the infinite number available. The alarm feature will recall the watch officer to the task should he be distracted by other watch routine.

System Costs

A typical system cost is $175,000.

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RADAR PILOTING PREDICTOR

System Definition

An electronically generated video presentation on the radar scope which predicts in graphic form the future effect of changes in rudder angle and speed of a vessel.

System Description

This device, designed by Eclectech in North Stonington, Connecticut, was created to aid in piloting vessels in restricted waters and has been used to train Sandy Hook Pilots. It consists of a cathode ray tube (CRT) made to resemble a radar scope by means of a cardboard template inscribed with a compass rose. Knobs on the scope permit orders to the rudder and engine to be introduced. A computer program simulates the hydrodynamic characteristics of an 80,000 DWT vessel which is transiting a harbor channel. A specific channel is simulated with buoys and targets to add to the reality. A predictor device, also mounted on the CRT, gives a visual presentation up to three and a half minutes in the future of the effects of course and speed changes.

System Capability

Although this simulation system is experimental, it is uncomplicated and presents a realistic, dynamic, radar display which is easy to use. With little indoctrination, an experienced shiphandler can make effective use of the predictor to conn the ship in a narrow channel.

System Accuracy

This is dependent upon the accuracy of the gyro, pitometer log and hydrodynamic characteristics which are introduced in the system.

System Advantage

It is a very simple, quick method to determine in advance the reaction of the ship to changes in rudder angle and speed when maneuvering in restricted areas. It helps supplement the "seaman's eye" which is so important, and sometimes faulty, when handling the ship in close quarters.

System Disadvantages

It is in a very early development stage. Resources will be necessary to evaluate its usefulness. Disadvantages may develop later, which are not now

apparent, as system design progresses from a simulation stage to actual installation and use on board ship.

Mitigative Potential

A practice transit of Arthur Kill and Kill Van Kull by a PRC representative with shiphandling experience demonstrated that the device is easy to use and a very effective piloting tool in restricted waters. This device appears worthy of further evaluation.

System Costs

Not known, experimental system

Bibliography

Visit to Eclectech, North Stonington, Connecticut, February 1978.

CONSOL

System Definition

Consol is primarily a low accuracy, three antenna, long range azimuthal system. Its primary use has been for air navigation. It is a hyperbolic system operating in the range of 250 to 350 kHz. It differs from Consolan in the fact that cycles of varying lengths are used rather than continuous wave or CW. Consol is a European system, having been invented by the Germans during World War II.

System Description

A Consol System is made up of three transmitters in line, equally spaced at three times the wave length of the transmitted frequency. Radial patterns of alternate dots followed by dashes are followed by an equisignal or silence. The operator will hear equisignal once every transmission cycle. A count of dots and dashes gives the angular position within a sector or a line of position (LOP). The sector itself has to be identified by RDF or some other form of radio navigation. As in Consolan, there is a blind sector extending from the baseline of about 30°. Most accurate bearings are obtained at 90° from the baseline.[1]

The signal from the Consol transmitter consists of two parts, the transmission of the call sign, sometimes with a continuous wave signal, and the transmission of the rotating pattern, which is what is observed. The duration of the total transmitting cycle is not the same for all stations, but the rotating period has been standardized at 38 seconds. If the call sign only is sent in addition to the rotational cycle, the total signal duration is 40 seconds. When the continuous wave signal is incorporated, the total signal duration is 60 seconds. The call sign and the continuous wave signal are transmitted from the middle antenna of a Consol system.

Some special adaptors and receivers have been produced for use with the system. These aid in the counting of the dots and dashes. One such method uses a meter indication in which dots give a deflection to the other side. There is also an automatic Consol receiver, which shows digital readout of the dot and dash count. This receiver can compensate, within error limits, for missing characters when the equisignal condition is masked by noise.

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[1] Dutton's Navigation and Piloting, 12th Edition, Annapolis, Maryland: Naval Institute Press, 1972, p. 327.

Instructions for use of the system are contained in DMAHC Pub. 117. Special Consol charts are required for its use.

There are seven Consol stations; all are located in Western Europe and the Soviet Union, along the Arctic coast in the case of the latter.

System Capability

Under favorable conditions the area of coverage of a Consol station over water extends outward for about 1,000 to 1,200 nautical miles in the daytime,[1] and 1,200 to 1,500 nautical miles at night. In general, when ground waves are received, the error over water does not exceed about one-third degree along the perpendicular and about two-thirds of a degree at an angle of 60^{o} to the perpendicular similar to Consolan. Stated in nautical miles, this is an error of about one nautical mile for each 180 nautical miles from the station along the perpendicular, and for each 90 nautical miles along the bearing line 60^{o} from the perpendicular. This error can usually be reduced by taking a number of bearings, and averaging the results.

System Accuracy

The accuracy of the system depends on the number of dot and dash sectors. It follows therefore the accuracy of the Consol LOP depends on the baseline length between each antenna, which is an integral number of wavelengths, usually three. If the number of wavelengths is increased, the blind sector is reduced. The accuracy[2] can be as good as $.33^{o}$ or less along a perpendicular to the baseline at a range of the order of 1,000 to 1,200 nautical miles in daytime. At night this drops to $.7^{o}$.

System Advantage

The advantages of Consol are the following:

- Simple radio receiving equipment can be used with a long antenna and a beat frequency oscillator.
- Long range system that can operate in virtually all weather.
- A communications CW receiver can be used.
- Good accuracy under adverse signal to noise ratio.

System Disadvantages

The disadvantages of Consol are the following:

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[1] Dutton's Navigation and Piloting 12th Edition. Annapolis, Maryland: Naval Institute Press, 1972. p. 329.

[2] Ibid

- Two ambiguous zones of about 30^o centered on the baseline cannot be used for LOP determination.
- Requires good operator skill.
- Cannot be used closer than 25 to 50 miles from stations.
- Is not highly accurate.
- It is only an ocean navigation aid; is not accurate enough for making landfall.
- Essentially a European system.

Mitigative Potential

Because the accuracy of the system near shore is so limited and because of blind sectors, the system would not be indicated for DWP use, except perhaps as a backup in the approaches to the Florida Straits. It does, of course, offer receiver simplicity. This system is European, with no sending stations in the United States.

System Costs

The costs of Consol receivers would be less than $500.

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CONSOLAN

System Definition

Consolan is a long range hyperbolic radio receiver navigational aid operating on a frequency of 192 kHz. The system receiver requires a beat frequency oscillator. Consolan is a continuous wave (CW) system.

System Description

Consolan is a two antenna system that allows determination of ship's bearing or LOP from the transmitters. It uses a pattern of alternating dot and dash sectors separated by silence. The width of a sector is about 12^{o} differing slightly with respect to the position of the tower baseline. The most accurate position occurs at 90^{o} from the baseline while 0^{o} and 180^{o} give unusable sectors. Charts giving the various dot and dash sectors are available. On a Lambert chart the bearing can be plotted directly. On a Mercator chart a correction must be made to allow for the great circle travel of radio waves.

System Capability

Consolan is an audio or listening system, hence depends heavily on operator experience and skill. Since the human ear and mind can often pick a signal out of a noise to signal ratio that is large, good accuracy can sometimes be obtained on this system. The range of the system depends on:

- Electronic noise present
- Ground conductivity
- Ionospheric conditions
- Frequency and power of ground stations
- Operator's aural acuity

The usable range of the system is of the order of 1,400 nautical miles as a maximum and 50 miles as a minimum.

System Accuracy

Consolan accuracy on a line 90^{o} from the tower baseline is $.30^{o}$ by day and $.7^{o}$ at night.

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[1] Dutton's Navigation and Piloting 12th Edition. Annapolis, Maryland: Naval Institute Press, 1972, p. 328.

[2] Ibid

System Advantages

The advantages of Consolan are the following:

- Simple radio receiving equipment can be used with a long antenna and a beat frequency oscillator.
- Long range system that can operate in virtually all weather.
- A communications CW receiver can be used.
- Can obtain good accuracy under adverse signal to noise ratio.

System Disadvantages

- Two ambiguous zones of about 30° centered around the baseline cannot be used for LOP determination.
- Requires good operator skill.
- Cannot be used closer than 50 miles from stations.
- Is not highly accurate.
- It is only an ocean navigation aid; is not accurate enough for making landfall.

Mitigative Potential

Because the accuracy of the system near shore is so limited and because of blind sectors, the system would not be indicated for DWP use, except perhaps as a backup system in the approaches to the Straits of Florida. It does, of course, offer receiver simplicity.

System Costs

Cost of a Consolan receiver is less than \$500.

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NAVSAT

System Definition

NAVSAT, Navy Navigation Satellite System is a United States Navy operated and developed Satellite System. It is an all weather, worldwide passive navigational system for ships and aircraft. It is also available to commercial vessels.

System Description

NAVSAT operates on the principle of the Doppler shift, that is, the observed change in frequency caused by relative motion between moving satellite and relatively stationary vessels. Approaching, the frequency increases, while receding it decreases. The amount of shift depends on the exact location of the receiver with respect to the satellite, hence if the orbit of the satellites is known to a high degree of precision, it follows that measurement of the Doppler shift at the receiver will allow determination of the location of the receiver on the surface of the earth.

The NAVSAT system consists of several satellites, ground tracking stations, a computer system, an injection station, two signals, and ships' receivers and computers.

Satellites orbit at 600 miles above the earth every 105 minutes and store data, which is updated from a ground station, twice a day. Every two minutes each satellite broadcasts both the fixed and variable parameters of its own orbit, plus a time reference. These transmissions are on two frequencies, 150 and 400 MHz to correct for ionospheric electromagnetic dispersion.

A satellite fix is obtained when satellite altitude relative to observer is above 15° altitude and less than 75°. A single satellite will yield four fixes a day. An increase in the number of satellites aloft will increase the number of fixes that can be made.

The United States Naval Astronautic Group in Point Mugu, California, supplies information on the operational status of satellites to mariners by means of SPATRAK messages.

Perturbations in the satellite orbit are corrected for by computer in the ground station. Time corrections are made by comparison with corrected universal time (UT_2).

Computation of an orbit that best fits the Doppler curve obtained by the four ground tracking stations is made by the computing center. Orbital information is then

extrapolated to give satellite position every two minutes for the next sixteen hours and this data is in turn fed back at the injection station for transmission to the satellite every twelve hours. The satellite stores this information in its memory system.

To obtain position fixes the estimated position and velocity are entered into the ship's computer. High accuracy in velocity determination is obviously important, since this contributes to a small error in Doppler shift determination, and hence high position accuracy. At the point of closest approach the frequency shift is zero.

To calculate a position fix the frequency count and satellite information are fed to the computer along with position and velocity. The frequency difference (estimated) is also fed to the computer. The computer compares calculated range distances between satellite and ship with those measured by the frequency shift and the navigation fix is obtained by searching for those coordinates plus frequency difference which make the calculated range difference fit best with the measured range difference. Thus, the range differences play the role of dependent variable; ship's position and velocity, satellite position, velocity, and time play the role of independent variables. A best fit or regression of range difference with respect to independent variables yields an estimate of positions. The fit is a linear one, which is carried out by computer and takes on the order of seven minutes to complete.

System Capability

The area of coverage of the system is worldwide, although high latitude reception can result in interference, since the satellite orbits cross at the poles. In lower latitudes, fixes are less frequent; on the order of one hour.

System Accuracy

Accuracy is of the order of 150 meters and more recent systems contemplate accuracies of the order of 90 meters.[1]

System Advantages

- High accuracy.
- Reliable in all weather.
- Can be made automatic.

System Disadvantages

- Fixes are not continuous, especially near equator.
- Requires precise ship velocity determination.
- Requires expert maintenance.

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[1] Dutton's Navigation and Piloting, 13th Edition. Annapolis, Maryland: Naval Institute Press, 1978. p. 760.

Mitigative Potential

A future development wherein correction information obtained from receivers in known positions and transmitted via land or satellite radio could be useful where dense traffic or other hazards has led to routing schemes to and from and in approaches to DWP areas. More satellites are required to provide shorter intervals between fixes however. Trained people are also required for the system as well as a commitment to sophisticated shipboard equipment.

Simulation of the inclusion of such a system aboard ship could be made via the TSC vessel model where, again, reduced uncertainty in ship's position would be the variate that would determine the change in probability of collision, ramming and grounding.

System Costs

$35,000.

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NAVSTAR

System Definition

The NAVSTAR is a multiservice program run by the United States Department of Defense. The program provides for an evolutionary and conceptual approach toward the development of an air and sea navigational, global positioning system. The objective of the approach is to enable a user to position himself within ten feet anywhere on the globe.

System Description

The NAVSTAR system consists of three segments: the space segment, ground segment and user segment. For the first phase of the program, the Concept Validation Phase, money has been funded to provide five NDS satellites, which when added to the NTS II satellite developed by the U.S. Naval Research Laboratory, will comprise a constellation of two planes of three satellites each in an 11,000 mile (12-hour period) orbit.

The ground segment consists of four monitoring stations, a master control station and an upload station. The user segment presents the design and development of different classes of receivers to satisfy user requirements.

The satellites continuously transmit ranging information on two L-band frequencies. In order for the user to determine his position, the system requires the determination of the transit times for satellite generated signals to reach the user. Satellite position, frequency standard states, and other necessary information are determined by the ground stations and transmitted to the satellites for modulation onto the navigational signal. The computer within the users' receiving set contains the algorithms which convert transit times and system data into clock corrections, user position coordinates, and velocity.

Monitoring stations located at Vandenberg AFB, California, Alaska, Hawaii and Guam will track the satellites in view and determine ranging data from the navigation signals transmitted by the satellites. This information is then processed by the master control station to determine the best estimate of satellite ephemeris and clock drift relative to system time. An upload station, located at Vandenberg AFB during Phase I, will transmit the ephemerides, clock update and ionospheric corrections to the satellite once a day.

The concept of determining the desired system position accuracies is based on the technique of making transit time measurements similar to NAVSAT of RF signals

encoded as pseudo random noise modulation on an L-band carrier. A very accurate timing system carefully synchronized must be used. Timing stability is obtained from a medium frequency standard.

The user requires at least four satellites in view simultaneously at 5° above the horizon. The simultaneous reception of four signals will produce four independent range difference equations, which can be used to determine the clock bias and calculate the position at the intersection of four hyperboloids of revolution. If more than four satellites are available, one will use the four satellites which give the greatest precision.

System Capability

The NAVSTAR program is presently in the system test and limited capability phase. This means that the start of a two dimensional navigation capability comprising 9 to 11 satellites has been initiated. Completion of this capability would be in 1981. Coverage of course will be worldwide with such a system.

System Accuracy

The system accuracy of NAVSTAR when fully operational is to provide position within 8 meter horizontally and 10 meters vertically, velocity to .1 knot and time to a fraction of a microsecond.

System Advantage

- High position accuracy on continuous basis.
- All weather system.
- A precision time standard will be available. Loses 1 second every 72,000 years, so it is claimed.

System Disadvantages

- System not yet operational.
- System may never be operational depending on budget limitations.
- Receiving equipment complex.

Mitigative Potential

The system is definitely in the futuristic category. It is claimed that eventually a 37 foot worldwide accuracy can be obtained along with a time standard that loses one second every 2.5×10^6 years. Obviously both these specifications far exceed the needs of marine safety since the size of VLCC and ULCC vessels exceed the length dimension by one and one half orders of magnitude and therefore tends to

wash out the accuracy (steering uncertainty for example). For small military aircraft or missiles, on the other hand, such precision is not wasted.

In any case it would be interesting to simulate ship movement with such precision on the TCS model and determine the reduction in collision, grounding and ramming probability. With the precision claimed, such a system could form the basis for an automated ship control system, centrally operated, for the DWP area. If the control system can dynamically live up to the NAVSTAR precision, then the high accuracy can be utilized. This would be far in the future, however.

System Cost

Not known or available at this time.

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Aerospace and Flight Test Radio Coordinating Council, Meeting #63, Tucson, Arizona, 1976.

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SHIP INERTIAL NAVIGATION SYSTEM (SINS)

System Definition

This is an all weather, dead reckoning system, using gyroscope, accelerometer, and electronic-solid state circuitry to sense turning rates, accelerations of the earth, and ship's movement relative to the earth. A continuous readout of ship's position, heading, roll, pitch and speed is obtained.

System Description

Inertial systems are based on the fact that gyroscopes and accelerometers have a mechanical orientation in accordance with the laws of classical Newtonian and Lagrangian mechanics. All deviations from a reference orientation are sensed and measured with the appropriate instrumentations. The following components make up the system:

- Gyroscope
- Accelerometers
- Computers

The gyroscope uses three axes to stabilize a reference platform from which the accelerometers measure deviation. The gyros are not fixed in space. Gyro corrections are made from time to time to ensure that a prior reference is maintained.

The accelerometers measure accelerations, and if equipped with a device that can integrate with respect to time, can measure velocity and distance as well.

The computer system performs the necessary mathematical functions, such as integration, and the processing of external position fixing information from NAVSAT, etc., for recalibrating the system.

System Capability

SINS will give a continuous readout of position, heading and velocity. It can be used in conjunction with other navigational or sighting systems where accurate horizon reference or horizontal stability is needed.

It has a sensitivity of several seconds of arc as a rate of precision in response to a small input torque, and a rapid response capability of several degrees of arc per second in response to ship's roll and pitch.

System Accuracy

Position accuracy of SINS when all system errors are taken into account is thought to be high. This is a dead reckoning result and not a fix in the normal sense.

System Advantages

- Gives heading and speed information continuously with high accuracy.

System Disadvantages

- Is a DR instrument, which must be updated periodically, using other position fixing methods, and can therefore propagate and extend error.
- Complicated system which requires precision maintenance.
- Detailed information concerning the system is classified.
- Advantages seem to lie chiefly in use on submarines, where frequent position fixing is not always possible, and other military applications.

Mitigative Potential

The mitigative potential and practical shipboard use of SINS would seem to lie in the area of automatic star tracking and ship's velocity information for satellite navigation. Used in this way high precision position fixing can be obtained on a basis that might be competitive with differential Omega. The high cost of the system and the high maintenance requirements, however, tend to offset this advantage.

System Costs

Not known, but believed to be very high.

Bibliography

Dutton's Navigation and Piloting, 13th Edition. Annapolis, Maryland: Naval Institute Press, 1978.

Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrographic Center, 1977.

DOPPLER NAVIGATION SYSTEM

System Definition

The Doppler navigational system manufactured by Raytheon is a sonic energy transmitting system using four transducers to compare return signals and computed course direction and speed made good over ground.

System Description

The Doppler navigational system employs four beams of sonic energy, spaced 90° apart. These beams are directed outward and downward at equal angles of inclination from the horizontal. The sonic energy is transmitted from transducers, which are activated by an electrical signal from the transmitter. In addition to radiating the outgoing sonic signal, the transducers serve as hydrophones, in that they also pick up the echo of the signal, reflected from the ocean floor, and convert the acoustic echo into electrical energy. This energy passes into the receiver, where it is amplified, and the input from the four transducers is compared to produce the Doppler frequency. It also determines the relative height of the frequencies, thus providing a sense of ship motion and its direction.

To make it a true navigational system, the transducer array is constantly oriented to true north by the ship's gyrocompass, which also serves to stabilize the array, and maintain it in a horizontal plane, regardless of any roll or pitch. Motion is now indicated in the north-south and east-west directions, and readout is both the true direction and distance traveled from a point of departure expressed as distance north or south and east or west. Therefore, the system can present a constant indication of position, expressed as latitude and longitude, and can also continuously plot position on a chart, using an X-Y coordinate plotter.

System Capability

A good gyrocompass under good operational conditions will have a bearing uncertainty of .1°.[1] The Doppler navigational system using a heading reference in which this error remained constant would indicate a position claimed to be about 0.17 percent of the distance traveled from the departure. Thus, the ship might be to the right or left of the intended track by this amount. As the errors introduced by the gyro usually tend to be normally distributed rather than constant, they average out to a considerable extent. Many runs have been made with this equipment to a considerably higher degree of accuracy than the 0.17 percent error would seem to indicate.

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[1]Dutton's Navigation and Piloting, 13th Edition (Annapolis, Maryland: Naval Institute Press, 1978) p. 800.

The system is limited to water depths not exceeding 1,000 feet.

System Accuracy

Accuracy of the system is .17 percent of the distance traveled from departure.[1]

System Advantages

- Highly accurate DR system.
- Volume reverberation, sea return from the water rather than the bottom can sometimes be used in depths exceeding 600 feet.
- Due to great stability of VLCC gyro stabilized system can be omitted. Stabilization is achieved by electronic means aboard ship.

System Disadvantages

- System is complex and still somewhat experimental.
- Not generally effective in deep water.

Mitigative Potential

Marine Doppler navigation systems are still in the early stages of development. It seems highly probable that their performance and efficiency will be further improved. Doppler navigation will probably be limited in use to specialized ships, but for them it should prove to be a most useful backup to their overall navigational capability.

For the VLCC, Doppler equipment can furnish a continuous and accurate DR plot at sea; it is of even greater benefit when entering or operating in port. Due to the great draft of these ships, often well in excess of 75 feet, they cannot rely on the usual channel markers to keep in safe waters. Instead, they must often restrict their movements to the deep portion of the normally used channels. The Doppler system can be of great assistance in such operations, and can often warn of potential trouble before it can be detected by plotting visual bearings.

In docking, pilots and masters have frequently experienced difficulty in sensing slight lateral motion in VLCC's during the final stages of coming alongside a fueling berth or SPM. Due to the tremendous mass inertia involved serious damage can result from even a comparatively slight contact with a structure.

To detect such motion, a pair of transducers are installed well aft. These are placed on the athwartships axis, and are intended solely to detect lateral or turning motion when coming alongside, and when the engines are stopped.

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[1] Dutton's Navigation and Piloting, 13th Edition. Annapolis, Maryland: Naval Institute Press, 1978. p. 800.

As such the Doppler equipment offers both a navigational and a berthing or narrow channel advantage. Simulation of the latter could be made to assess the change in grounding probability by its use in narrow channels.

System Costs

Not known but believed to be high.

Bibliography

Dutton's Navigation and Piloting, 12th Edition. Annapolis, Maryland: Naval Institute Press, 1972.

Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrographic Center, 1977.

FATHOMETER AND SONAR

System Definition

Fathometers generate an underwater sound signal and measure the duration of time between the generation of the signal and the reception of the echo returning from the bottom. Sonar operates on the same principle, but usually sends its sound signal in a near horizontal direction. Detection of underwater objects is made as well as range and bearing determination.

System Description

The generation of underwater sound signals occurs in the range of 20 to 20,000 Hz, with a nominal speed of sound in water of 4,800 feet per second. The system is made up of the following components:

- Transducer

The transducer, located on a horizontal portion of a ship's bottom plating, near the keel, transmits the acoustic signal when activated electrically. The sound energy used to determine depth is projected in the shape of a cone at various solid angles being of the order of .677 solid radians, the area of the bottom covered by the cone of sound is a function of the depth, being equal to the depth squared times .677 of the depth, and in deep water it can be quite large. The returning echo is picked up by the transducer, converted into electrical energy, amplified and presented visually. Elapsed time between the outgoing and the returning signal is read directly as depth. The depth finder usually gives depth under the keel, so that the actual depth of the water is equal to the depth under the keel plus the draft of the ship. Alternately, it may be calibrated to indicate the depth of water as measured from the surface.

- Readout

In a typical instrument, a circular electric light tube is mounted vertically; this tube flashes briefly at the instant the sonic signal is transmitted, and again when the echo is received. In front of the light tube, and mounted concentrically with it, is an opaque shield, which rotates at a predetermined speed. This shield has a narrow radial slot, which allows the light to be seen at only one point each time it flashes. Adjacent to the shield is a circular scale calibrated in units of depth. The depth finder shows the first flash of light at the zero point on the scale, and the second flash indicates the depth of water. Different scales may be available for use at various depths; the speed of rotation of the opaque shield is adjusted to match the scale being used.

- Recorder

Some echo sounders are also equipped with a recorder which produces a graphic trace of the depths encountered; this trace is called a bottom profile. The recorder consists of a wide paper tape, graduated in depth and time units, and a moving arm equipped with a stylus, which makes one sweep over the tape for each sounding. When the echo is received the stylus marks a short line on the tape.

System Capability[1]

A new United States Navy system known as the UQN-4 operates on a frequency of 12,000 Hz and contains all solid state electrical equipment. It sends out a pulsed continuous wave signal ranging from 120 pulses per minute in shallow water (600 feet) to 2 per minute in the deepest water. The respective short pulse durations are .33 to 20. milliseconds, while the long pulse rate ranges between 0 to 160 milliseconds. It can be operated manually if desired for selected inspection of underwater objects. It is also capable of automatic tracking.

System Accuracy

Accuracy is variable depending on temperature, density and marine life stratification and gradient.

System Advantages

System can be used to measure depth on a continous basis and used in conjunction with bathymetric map can be a backup dead reckoning system.

System Disadvantages

System subject to error and improper operation, and thus misinterpretation by inexperienced operators. False bottom readings caused by soft mud not reflecting signal properly could cause grounding accidents.

Mitigative Potential

All ships of United States registry over 500 gross tons are required to have a deep sea echo device onboard. Its utility for dead reckoning depends strongly on the bottom in the area of concern being well charted. Since this is not generally the case, such a method of DR does not have much to recommend it. Side ranging sonar could aid in detecting reefs and the like if monitored properly.

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[1] Dutton's Navigation and Piloting, 12th Edition. Annapolis, Maryland: Naval Institute Press, 1972. p. 631.

System Costs

Highly variable depending on system.

Bibliography

Dutton's Navigation and Piloting, 12th Edition, Annapolis, Maryland: Naval Institute Press, 1972.

Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrographic Center, 1977.

NAVIGATION DATA ASSIMILATION COMPUTER (NAVDAC)

System Definition

Navigation Data Assimilation Computer (NAVDAC) is a realtime (precise time or clock time) general purpose digital computer originally designed for the Polaris submarine program.

This computer has four primary functions--coordination of the control of all equipment in the entire system, data gathering for fixes from external sources, processing of fixed data for reduction to SINS reset parameters, resetting SINS and monitoring results.

System Description

From the four functions that are indicated above, it can be seen that NAVDAC is an integrator for various navigational instruments, including the inertial system, velocity measuring devices, gyro compass, radio aids, such as Loran, and celestial altitude measuring instruments, and so forth. It is in fact a central system for combining the individual components into a single operating system. Data from the individual input sources are processed by NAVDAC, drawing when necessary on the data storage or memory component, and the resultant information is used to determine the corrections to be applied to the SINS to indicate the ship's position and so forth. The data storage component has a tremendous capacity; for example, it stores the sidereal hour angle and declination for each of about 200 stars. All data are regularly updated as required.

System Capability

Since NAVDAC uses more than one fix determining instrument, it is able to filter the data received, correlate it and weigh it, make logical and statistical decisions, perform coordinate conversions and generate control functions. Consequently, a standard of accuracy and reliability previously unattainable is possible by means of redundancy from multi-data sources. In addition to all this, the computer is able to carry out self-checking procedures for verifying the large number of computations it has undertaken. NAVDAC has provided the accuracies commensurate with the requirements of marine navigation.

System Accuracy

When star observations are to be obtained, SINS supplies the vessel's DR position to NAVDAC. Using these data, as well as current instant of GMT and the

stored ephemeristic data on the selected star, NAVDAC supplies the star's computed altitude and azimuth and the rate of change to the other components. Concurrently SINS establishes the vertical by feeding continuous information on roll and pitch angle to the other components, which combines this information with star data to keep the periscope's line of sight continuously pointed in the star's direction. Star acquisition is obtained immediately due to the accuracy inherent in the system. As the field of view is small, ordinarily the desired star will be the only one to appear. Since NAVDAC was developed in conjunction with the Fleet Ballistic Missile Nuclear Submarine Program, the requirement for accuracy was extremely high. Thus, the system developed is one which allows an extremely accurate position fix to be made by a vessel so equipped.

System Advantages

The primary advantage of NAVDAC is its extremely accurate and reliable position fixing. Since it can be used in conjunction with a SINS or with a startracker periscope and still retain the high degree of accuracy, it provides a capability to accurately fix positions regardless of weather conditions.

System Disadvantages

The primary disadvantage of NAVDAC and its associated equipment is the highly complex nature of the equipment. The level of maintenance for shipboard use is extremely high and requires that individuals be specially trained to be able to operate and maintain the equipment. Since the equipment works on a major power supply, in the event of failure of that supply, a secondary source of power must be provided in order to permit the NAVDAC to function.

Mitigative Potential

The primary mitigative potential inherent in NAVDAC is its ability to compute highly accurate positions of the vessel, thus nearly eliminating probability of the vessel being involved in a casualty as a result of poor position fixing information.

System Costs

Not known or available.

Bibliography

Dutton's Navigation and Piloting, 12th Edition, Annapolis, Maryland: Naval Institute Press, 1972.

MINIATURE INERTIAL NAVIGATION DIGITAL AUTOMATIC COMPUTER (MINDAC)

System Definition

The Miniature Inertial Navigation Digital Automatic Computer (MINDAC) is a microelectronic general purpose digital computer and is incorporated in the ship's inertial navigation system (SINS).

System Description

Star altitude data is obtained from the star tracker and is reduced to positioning information in MINDAC, which can store ephemeristic data for 80 of the brightest stars in both the northern and southern hemispheres in its memory section. Memory capacity for storing a Loran-C program or other data can also be added.

Orientation data from SINS processed through the computer and combined with star position data is used to initially align the star tracker's telescope to the star position. After the star has been detected by the tracker, tracker error signals, measured by the startracker, are used to torque the tracker's traverse and elevation gyros to center the star on the tracker's line of sight. After being aligned by the signals from SINS, the star tracker remains space oriented to the line of sight to the star by the use of gyros mounted in each gimballed axis. This orientation is maintained even though the ship's motion is constantly moving the bedplate. MINDAC then takes a series of star shots by freezing (simultaneously sampling) tracker trained and elevation readouts and reduces these data from several stars to reset the SINS.

System Capability

MINDAC is designed primarily to calculate present ship's position from heading velocity and input data and to provide appropriate bias and torquing signals to the gyros in order to maintain the SINS inertial platform aligned to the vertical. In addition, it provides periodic readouts of the ship's velocity and position to the central data processor and resets the platforms to the correct position when necessary at the operator's command.

System Accuracy

When MINDAC is functioning with the SINS, a highly accurate system results. Because a greatly improved stable platform to provide the vertical was required for shipboard use, NASA designed such a combined instrument for its range instrumentation ships. In these ships, vertical reference and stability about three axes have been obtained by combining the startracker with a deck-mounted ship inertial

navigation system (SINS), an integral part of the integrated navigation system. Experience has shown that the cooperative action of different types of navigation systems permits obtaining an overall performance considerably better than the sum of the outputs of the individual systems. This synergistic advantage is particularly appropriate when a startracker system is combined with an inertial system. A combination of this type permits bounding of the inertial system errors which accumulate as a function of time, and complete realignment of the inertial system when required. The combining of the two units therefore produces an improved overall result. The way in which the component parts of the total system are arranged eliminates errors caused by flexure of the ship, which would occur if the two units were separately installed at different locations. The vertical established by SINS is a precision reference, essentially free from bias errors; it is achieved by accelerometer monitoring.

System Advantages

The advantages of utilizing MINDAC in conjunction with the integrated navigational system provides a means for accurate position fixing on the ocean's surfaces. The system is required to operate with a relatively complex set of peripheral gear; however, the combination of the equipments that are utilized provide the distinct advantage of permitting accurate position fixing by highly accurate instruments, thus reducing the error that can accumulate in a navigational plot due to human errors.

System Disadvantages

Primary disadvantage of the utilization of MINDAC and its associated equipment is that the complexity of the equipment requires an extremely high level of maintenance. The entire system is totally dependent upon an electrical power supply, which might fail, thus requiring a standby power system for continued utilization of MINDAC. When MINDAC is used in conjunction with the startracker and inertial systems, storms and other forms of overcast skies preclude the startracker from performing its functions.

Mitigative Potential

The potential for accurate position fixing of vessels is greatly enhanced in the utilization of MINDAC and its associated SINS equipment.

Because of this accurate position fixing, it is highly likely that casualties resulting from navigational errors would be greatly reduced if this type of equipment were available to a large number of oceangoing vessels.

System Costs

Not known but believed to be high.

Bibliography

Dutton's Navigation and Piloting, 12th Edition, Annapolis, Maryland: Naval Institute Press, 1972.

RADIO DIRECTION FINDING (RDF)

System Definition

RDF systems use a non-directional transmitter and a direction sensitive antenna system for the receiver. Bearings are obtained from other ships, planes, shore stations, marine radio beacons, and coastal stations, as well as commercial broadcasting stations. If the location of the transmitter is known, a bearing can be taken on it.

RDF is the oldest radio navigational aid for determining bearings and fixes, and is the only compulsory radio aid on vessels over 1,600 tons in international trade.

System Description

A radio direction finder utilizes the directional properties of a loop antenna. If a loop antenna is parallel to the direction of travel of the radio waves, the signal received is of maximum strength. If the loop is perpendicular to the direction of travel, the signal is of minimum strength or entirely missing. When a dial is attached to such a loop antenna, the direction of the antenna and hence the direction of the transmitter can be determined. The pointer indicates the direction of the transmitter from the receiver when the loop is perpendicular to this direction, when the minimum signal is heard. The minimum, generally called the "null," rather than the maximum, is used because a sharper reading is thus obtained. Since radio waves travel a great circle, a correction must be applied for plotting on a Mercator projection chart. A Lambert conformal projection chart permits direct plotting of all radio bearings.

In certain foreign countries radio direction finder equipment is installed at points ashore and these radio direction finder stations obtain and furnish bearings of ships upon request. Such stations are also called radio compass stations. They can be identified and located by consulting H. O. 117 or by noting the symbol RDF on a navigational chart. If a sound signal is synchronized with the radio signal, through water distance from station can be determined. Such stations are called distance finding stations.

System Capability

The range of an RDF is determined by the strength of the radiated signal. Sensitivity of receivers is also paramount in range determination. Selectivity is also an important measure of capability since it indicates how well the receiver can lock in on one station. Radio beacons broadcast in a range from 200 to 415 kHz and 1880 to 2000 kHz.

Practical range in the frequency band just mentioned is of the order of 100 miles during daytime, making it a local coverage type of system. A radio beacon operates during all periods either sequenced or continuously regardless of weather conditions.

An interesting variation on the RDF concept is known as ADF, automatic direction finding. The antenna is locked on the station by electromechanical means, while the ship is moving. This automatic track is aided by the fact that all radiobeacons superimpose identifying characteristics on the carrier, which is on continuously during the period of transmission.

System Accuracy

Accuracy of RDF depends on the following factors:

- Strength of signals.
- Skill of operator.
- Calibration, especially on steel ships.
- Resolving reciprocal bearing error.
- Time of day.
- Nearness to land.

System Advantages

RDF has the following advantages:

- It is already in existence on virtually all large commercial vessels.
- It is simple, cheap and reliable.
- It can be automated.

System Disadvantages

RDF has the following disadvantages:

- It is not highly accurate.
- It can lead to disastrous results by taking reciprocal readings.
- Two or more stations must be received to determine a position fix.

Mitigative Potential

In order to have mitigative impact with regard to collision, ramming and grounding, four RDF requirements must be met:

- Accuracy in frequency settings.
- Quick identifications of radio stations.
- Accuracy in readings of bearings.
- Frequency tuning can be performed within the band 70 to 3500 kHz and have accurate display of actual frequency being received automatically if possible.

There are systems available that meet these requirements, however, the accuracy of such a system is not good enough to let it compete with Loran-C. It would thus serve as a backup system.

System Cost

The cost of an automatic direction finder receiver is of the order of $1,200.

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Dutton's Navigation and Piloting, 12th Edition. Annapolis, Maryland: Naval Institute Press, 1972.

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BRIDGE-TO-BRIDGE RADIOTELEPHONE

System Definition

This is the capability which permits operators of approaching vessels to communicate their intentions to one another through voice radio.

System Description

Every power-driven vessel of 300 GT and upward (and others, see 33 CFR 26.03), while upon the navigable waters of the United States shall have a radiotelephone capable of operation from its navigation bridge. This radiotelephone shall be capable of transmitting and receiving on International Maritime Mobile Channel 13 (156.650 MHz) and is for the exclusive use of the master or the person designated by the master, who shall maintain a listening watch on the frequency. No person may use the services of or may serve as the person required to maintain a listening watch unless he can speak the English language.

System Capability

Enables operators of approaching vessels to communicate their intentions to one another through voice radio.

System Accuracy

Not applicable.

System Advantages

Allows the resolution of doubt concerning the intentions of an approaching vessel, with an attendant reduction in hazard.

System Disadvantages

Monitoring this channel on the bridge, which is a "party line," adds to the noise level on the bridge, since most transmissions are for other vessels.

Mitigative Potential

Reduces risk of collisions by permitting approaching vessels to resolve doubt concerning each other's intentions.

System Costs

$500.

Bibliography

33 USC 1201 et seq. (Vessel Bridge-to-Bridge Radiotelephone Act 33 CFR 26.03).

RADIO SEXTANT

System Definition

The radio sextant is an instrument that utilizes radio frequency waves rather than visible light to determine position. Radio waves are emitted from both the sun and moon at 9 cm and 2 cm wave lengths.

Collins Radio Corporation produces a radio sextant that operates in the 2.2 cm wave length region. This sextant is part of the Ship's Self-Contained Navigation System, SSCNS, and would have to be termed futuristic.

System Description

The discovery that the sun and the moon emitted radio waves of lengths that could be received by antenna arrays of acceptable size for shipboard use suggested that these emissions might be used to augment conventional celestial navigation. Research was begun with a view to developing satisfactory receivers, as well as miniature radio telescopes capable of defining precisely the circumference of the disc of the sun or moon, from which the signals emanate. Instrumentation capable of sensing the vertical accurately was also required, as the primary purpose was to develop a celestial system which could be used when poor visibility made it impossible to obtain optical observations. As a result of this work, the radio sextant and SSCNS have been developed.

The sextant itself consists of two principal units -- radiometric acquisition unit, and control console -- which can be installed in three different locations. The deckmounted radiometric acquisition unit consists of a roll, pitch, bearing, and altitude gimbal structure, a microwave radiometer, and an antenna covered by a rigid spherical radome. The sextant employs a radiometer which operates in the 15,300 to 15,400 GHz radio astronomy band.

When the sun and moon are to be tracked, the computer uses the ship's DR position, as supplied by the inertial system, and for the current time obtains ephemeristic data for the selected body from the memory section of the computer. With these data, it computes both altitude and azimuth, and subsequently automatically trains the antenna on the computed position of the body. A search follows until the body is found. The difference between the observed and computed altitudes and azimuths is used to update the inertial system. The body is continually tracked until it sets below the horizon. Refraction corrected altitudes are made every two minutes. In the SSCNS, the radio sextant serves to update the position recorded by

the inertial component of the system. This is achieved by feeding in continuous altitude and azimuth data. Essentially, it may be considered as determining position by providing a series of accurate running fixes continuously obtained from observations of a single body, and integrated over a considerable period of time. This single-body method of operation is necessitated by the fact that only for very limited periods of the month are the sun and moon both above the horizon, and satisfactorily situated in azimuth to supply a conventional two-body fix.

System Capability

The SSCNS includes many features which make it highly acceptable for installation aboard vessels. It provides almost global navigational coverâge both by day and night, regardless of weather conditions, and it is self-contained, passive and highly immune to countermeasures. In addition to the radio sextant, it includes an inertial system and computer, and makes precise all-weather solar and lunar altitude and bearing data available to the navigator. The system operates satisfactorily when celestial radio inputs are interrupted; during such periods other navigational data may be inserted for updating the inertial system.

System Accuracy

SSCNS and the radio sextant accuracy is classified.

System Advantages

- Passive and continuous all weather system.
- Better accuracy than conventional celestial navigation.

System Disadvantages

- Can use only the sun and moon for fixes and both may be below the horizon.
- System believed to be expensive.
- Difficult to maintain.

Mitigative Potential

Although this system offers continuous all weather position determinations of apparently high accuracy, its size, cost, and maintenance needs, not to mention its ability to track only the moon and sun, make it a less than outstanding alternative mitigative measure.

System Costs

Not known but believed to be high.

Bibliography

Dutton's Navigation and Piloting, 12th Edition, Annapolis, Maryland: Naval Institute Press, 1972.

SHIP/SHORE RADIO COMMUNICATIONS

System Definition

Provides the capability for vessels at sea to deliver and receive messages by radio through an extensive system of government and commercial radio stations worldwide.

System Description

Practically all oceangoing vessels are radio equipped, since this is a requirement for vessels registered in countries which are signatory to the Safety of Life at Sea (SOLAS) Convention. The most common type of radio equipment found on these vessels is radiotelegraph, which is the SOLAS requirement; radiotelephone, however, is also widely used. The more modern larger vessels, notably tankers, also have high frequency single sideband radio equipment, and many have radio teletype equipment. Satellite communications, due to its high reliability, is also found on modern, sophisticated tankers and other large vessels in increasing numbers. The high cost and size of vessel satellite terminal equipment, however, has discouraged widespread use.

Ever since the development of the wireless telegraph by Guglielmo Marconi in 1909, the principal use of this equipment on board vessels has been for safety. Due to the extensive network of government and commercial radiostations worldwide, vessels today are seldom out of constant communication with shore facilities. In this country, the United States Coast Guard maintains an extensive watch on all of the international distress radio frequencies. Coast Guard radio stations are in direct communication with their associated rescue coordination centers and those of other nations. Calls for assistance to these stations bring rapid response in the form of medical advice, information concerning the location and capability of other vessels in the vicinity via the Automated Mutual Assistance Vessel Rescue System (AMVER), and depending upon the nature and seriousness of the emergency, dispatch of search and rescue vessels and aircraft.

System Capability

The ship/shore radio communications system is capable of providing continuous contact between vessels at sea and fixed communications facilities ashore, not only to conduct ship's business, but also, to summon assistance should this be necessary.

System Accuracy

System accuracy and reliability are a function of the communication path length, and the atmospheric conditions. Electromagnetic noise levels are generally

higher in the polar and tropical regions. Modern engineering techniques, particularly at the shore radio stations have been very effective in improving communication performance using, for example, high gain, highly directional antennas, and sensitive receivers.

System Advantages

- Permits rapid and continuous communication with shore radio facilities.
- Allows an internationally recognized and organized means of summoning assistance in emergencies.

System Disadvantages

- Requires radio receiving and transmitting equipment and, usually, a trained radio operator.

Mitigative Potential

In the Gulf of Mexico, Caribbean Sea and approaches, permits advance notification of arrival at a deep water port, to facilitate provision of pilot and service vessel facilities.

In addition, the following United States Coast Guard radio stations provide communication coverage of the area should emergency assistance be required.

Station	Bands Guarded	Working Frequency and Emission
Portsmouth, Virginia (NMN)	500 kHz	466 kHz 0.1A1
	2182 kHz	2670 kHz 6A3
	8 MHz	8465 kHz 0.1A1
	12 MHz	12718.5 kHz 0.1A1
	16 MHz	17151.2 kHz 0.1 (day only)
Miami, Florida (NMA)	500 kHz	440 kHz 0.1A1
	2182 kHz	2670 kHz 6A3
New Orleans, Louisiana (NMG)	500 kHz	428 kHz 0.1A1
	2182 kHz	2670 kHz 6A3
San Juan, Puerto Rico (NMR)	500 kHz	466 kHz 0.1A1
	2182 kHz	2670 kHz 6A3
	8 MHz	8471 kHz 0.1A1
	12 MHz	12700 kHz 0.1A1
	16 MHz	17002.4 kHz 0.1A1

Portsmouth, Virginia (NMN), and New Orleans, Louisiana (NMG), also guard the following single sideband (2.8A3 emission) ship transmit frequencies 24 hours a day:

Ship Transmit (kHz)		Coast Station Transmit (kHz)	
Assigned	Carrier	Assigned	Carrier
4096.2	4094.8	4394.8	4393.4
6208.6	6207.2	6523.2	6521.8
8228.2	8226.8	8762.2	8760.8

The following single sideband frequencies are also available at NMG and NMA on an "as needed" basis, but are not guarded:

Ship Transmit (kHz)		Coast Station Transmit (kHz)	
Assigned	Carrier	Assigned	Carrier
12366.4	12365.0	13145.5	13144.0
16496.4	16495.0	17291.4	17290.0

System Costs

Onboard receivers are of the order of $1,000 or less.

Bibliography

United States Defense Mapping Agency Hydrographic Center, Radio Navigational Aids, Pub. 117A and B. Washington, D.C., 1977.

RADAR BEACONS (RACON), RADAR MARKERS (RAMARK)

System Definition

Radar beacons (RACON) are radar receiver-transmitter devices which, when triggered by a surface search radar, automatically return a distinctive signal which can appear on the display of the triggering radar, providing range, bearing, and identification information. Radar markers (RAMARK) are transmitters which transmit continuously, or at intervals, information which appears on the radar display as a solid or broken line indicating the direction of the transmitter.

System Description

- RACON - provides both bearing and range information to target.
- RAMARK - provides bearing information only.

RACON must be triggered by the ship's radar in order to emit its own signal. Fixed frequency RACONS transmit on a single frequency which may be the same as, or different from, the ship's frequency. If the latter is the case, the ship's radar must be tunable to the beacon frequency or a special receiver must be used. In such a case, the PPI will, of course, be blank except for the beacon signal. Swept-frequency RACONS sweep across the entire 3 cm, or other radar band and can thus be used by any radar operating in the band.

In the United States only swept-frequency RACONS are used at the present time for marine aids to navigation.

RAMARK is a transmitter which transmits continuously, or at intervals, which appears on the radar display as a solid or broken line indicating the direction of the transmitter. There are few RAMARKS in use.

System Capability

RACON and RAMARK are all weather position and/or bearing determining aids which provide radar accuracy to fix determination.

System Accuracy

The accuracy of this system is linked to the accuracy of the radar receiver system and thus varies.

System Advantages

- All weather fix information.
- Easy identification of source.
- Can be used to estimate position quickly.

System Disadvantages

- Can fail to operate or be triggered.
- Can cause radar interference.
- Expensive when compared to radio beacons.

Mitigative Potential

The mitigative potential for radar beacons in the DWP area can be considerable with regard to identifying dangerous fixed structures and possible channel markers. Their use on oil rigs should lower the probability of ramming.

System Costs

Present RACON costs are approximately $15,000 each. Since RAMARKS are not used, cost is unknown.

Bibliography

Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrographic Center, 1977.

MARINE INFORMATION BROADCASTS

System Definition

Coast Guard radio stations make urgent, safety and scheduled marine information broadcasts, with virtually complete coverage of the approaches to the coastal waters of the United States, Puerto Rico and the Virgin Islands.

System Description

Coast Guard radio stations make two types of marine information broadcasts, radiotelephone for all seagoing users, and radiotelegraph for vessels carrying trained radio operators.

Scheduled radiotelephone broadcasts include routine weather, small craft warnings, storm warnings, navigation information and other advisories on working freqencies following a preliminary call on the voice international distress and calling frequencies. Urgent and safety broadcasts are made upon receipt of the information, urgent information is repeated 15 minutes later, both are included in the next scheduled broadcast unless cancelled before that time. Additional broadcasts may be made at the discretion of the originator.

Urgent broadcasts are preceded by the urgent signal: "PAN." Both the urgent signal and message are transmitted on 2181 kHz and 156.80 MHz (Channel 16). Safety broadcasts are preceded by the safety signal: "SECURITÉ." After a preliminary call on 2182 kHz, or 156.80 MHz, the station shifts to its assigned working frequency for the broadcast.

The following Coast Guard radio stations in the Gulf of Mexico area and its approaches make urgent, safety and scheduled marine information broadcasts preceded by a preliminary call on 2182 kHz or 156.8 MHz, at the times and on the working frequencies indicated:

Station	Working Frequency	Time (s)
NCF, Miami Beach, Florida	2670 kHz	0400, 0600, 0800, 1050, 1300, 1900 and 2250 EST
	157.10 MHz (Channel 22)	0630, 1230, and 1730 EST
NOK, Key West, Florida	157.10 MHz (Channel 22)	0600, 1200, and 1700 EST

NMA-21, St. Petersburg, Florida	2670 kHz	0920 and 2320 EST
	157.10 MHz (Channel 22)	0650, 1250 and 1750 EST
NMG, New Orleans, Louisiana	2670 kHz	0430, 0630, 1030 and 1630 CST
	157.20 MHz (Channel 22)	0450, 1050 and 1650 CST
NMG-15, Grand Isle, Louisiana	157.10 MHz (Channel 22)	0445, 1045 and 1645 CST
NOY, Galveston, Texas	2670 kHz	0450, 0650, 1050 and 1650 CST
NOY-3, Port Aransas, Texas	157.10 MHz (Channel 22)	0440, 1045, and 1645 CST
NCH, Port Isabel, Texas	2670 kHz	0440, 0640, 1040 and 1640 CST
	157.10 MHz (Channel 22)	0435, 1035 and 1635 CST
NMR, San Juan, Puerto Rico	2670 kHz	1100 and 2300 AST
	157.10 MHz (Channel 22)	0710, 1310 and 1810 AST

Scheduled radiotelegraph broadcasts include routine weather, small craft warnings, storm warnings, navigation information and other advisories on working frequencies following a preliminary call on the radiotelegraph international distress and calling frequency 500 kHz. Urgent and safety broadcasts are made: upon receipt of the information except with 10 minutes of the next silent period, for urgent messages only; during the last 15 seconds of the first silent period after receipt; and are repeated at the end of the first silent period which occurs during the working hours of one operator ships, unless the warning has been cancelled or superseded by a later warning message.

Urgent broadcasts are preceded by the urgent signal "XXX." Both the urgent signal and the message are transmitted on 500 kHz. Safety broadcasts are preceded by the safety signal "TTT." After the preliminary call on 500 kHz, the station shifts to its assigned working frequency to transmit the broadcast. The following Coast Guard radio stations in the Gulf of Mexico area and its approaches make urgent,

safety and scheduled marine information broadcasts preceded by a preliminary call on 500 kHz, at the times and on the working frequencies indicated:

Station	Working Frequency	Times
NMA, Miami, Florida	440 kHz	1100 and 2000 EST
NMG, New Orleans, Louisiana	428 kHz	1120 and 1820 CST
NMR, San Juan, Puerto Rico	466 kHz	1220 and 2120 AST

System Capability

The system provides information by both radiotelephone and radiotelegraph of urgent, safety and scheduled marine information, which is necessary to permit safe navigation of vessels in the Gulf of Mexico area and its approaches.

System Accuracy

The system provides accurate, timely information which is vital to safe navigation.

System Advantages

- Requires only a radio receiver for the voice broadcasts.
- Vessels at sea can obtain vital navigation information.

System Disadvantages

- Requires a trained radio operator to receive radiotelegraph broadcasts.
- Requires a continuous radio watch to receive urgent and safety broadcasts on their first transmission.

Mitigative Potential

This service provides timely warnings of dangers or special conditions to the mariner.

System Costs

Radio receiving equipment and, in the case of radiotelegraphy, a trained radio operator.

Bibliography

National Ocean Survey, United States Coast Pilot 5, Atlantic Coast, Gulf of Mexico, Puerto Rico, and Virgin Islands, Tenth Edition. Washington, D.C.: National Oceanic and Atmospheric Administration, 1977.

Defense Mapping Agency, Radio Navigational Aids, Pub. 117A, Atlantic and Mediterranean Area, Washington, D.C.: Hydrographic Center, 1977.

TECHNICAL SERVICES BROADCAST BY THE NATIONAL BUREAU OF STANDARDS

System Definition

Services included in the National Bureau of Standards broadcasts are: time announcements, standard time intervals, standard frequencies, propagation forecasts, geophysical alerts, marine storm warnings, UT1 time corrections and BCD time code.

System Description

The National Bureau of Standards (NBS) broadcasts time signals continuously, from radio station WWV, Fort Collins, Colorado, and WWVH, Kekaha, Kauai, Hawaii on 2.5, 5, 10, 15 and 20 MHz, and also 25 MHz from WWV only. The NBS also broadcasts time and frequency signals from its low frequency station, WWVB, located at Fort Collins.

Once each minute, time transmissions are made by voice from WWV and WWVH. A female voice is used by WWVH and a male voice by WWV to distinguish between the two stations. The WWVH announcement is made first, at 15 seconds before the minute, followed by the WWV announcement at 7½ seconds before the minute. Coordinated Universal Time (UTC) is used in these announcements.

The UTC time scale operates on atomic frequency, but by use of resets is changed to approximate the astronomical UT1 scale. Resets are necessary about once per year, and are usually made on December 31 or June 30. For those who need astronomical time more accurate than 0.7 seconds, a correction is encoded by use of double ticks after the start of each minute. (Consult Radionavigational Aids, Pub. 117, Defense Mapping Agency Hydrographic Center for further details.)

The most frequent sounds heard on WWV and WWVH are the pulses marking the seconds of each minute, except for the 29th and 59th second pulses, which are omitted. The first pulse of every hour is an 800 millisecond pulse of 1500 Hz. The first pulse of every minute is an 800 millisecond pulse of 1,000 Hz at WWV and 1,200 Hz at WWVH. The remaining seconds pulses are short audio bursts that sound like the ticking of a clock.

Storm warnings are broadcast from WWV by voice between 8 and 11 minutes after the hour, and from WWVH between 48 and 51 minutes after the hour. The format for these warnings is abbreviated. Example: "North Atlantic weather west of 35 West at 1700 UTC; Hurricane Donna, 24 North, 60 West, moving northwest, 20

knots, winds 75 knots; storm, 65 North, 35 West, moving east, 10 knots; winds 50 knots, seas 15 feet."

There are silent periods with no tone modulation, however, the carrier frequency, seconds pulses, time announcements, and the BCD times code continue. The silent periods extend from 15 to 20 minutes after the hour on WWVH, and from 45 to 51 minutes after the hour on WWV.

Propagation forecasts are given in voice at 14 minutes after the hour from WWV only. The propagation forecast is given as a phonetic letter and a numeral. The meanings of these symbols are:

Phonetic Letter	Meaning
Whiskey	Disturbed
Uniform	Unsettled
November	Normal

Numeral	Meaning
One	Useless
Two	Very Poor
Three	Poor
Four	Poor to fair
Five	Fair
Six	Fair to good
Seven	Good
Eight	Very good
Nine	Excellent

Example: "The radio propagation quality forecast at 0100 is good. Current geomagnetic activity is normal. The coded forecast is November Seven."

Geophysical alerts are broadcast in voice from WWV at 18 minutes after the hour, and from WWVH at 45 minutes after each hour. The messages are changed daily at 0400 UTC, supplemented by real time alerts of outstanding events.

WWVB broadcasts on 60 kHz with the same time format, frequency accuracy, and stability as WWV and WWVH.

System Capability

WWV and WWVH broadcasts cover most of the North Atlantic and North Pacific Oceans, while WWVB provides useful coverage within the continental United States.

System Accuracy

The time and frequency broadcasts are controlled by the NBS cesium frequency standards, with an accuracy[1] of 2 parts in 10^{12}. The frequencies transmitted by WWV and WWVH are held stable to better than 1 part in 10^{11}.

System Advantages

- Ships' chronometers can be calibrated accurately, improving the quality of celestial observations.
- Frequency standards can be calibrated allowing accurate measurement of radio frequencies in receivers and transmitters.
- Storm warnings can be monitored constantly.
- Unusual geophysical phenomena such as tsunamis and earthquakes can be monitored constantly.
- Propagation forecasts can be obtained which allow communication personnel to use alternate means of communications during solar storms.

System Disadvantages

- None apparent.

Mitigative Potential

Complete coverage of the Gulf of Mexico, Caribbean Sea, and approaches, permits vessels in these areas to take full advantage of this multipurpose service.

System Costs

Medium and high frequency communication receivers and antennas already installed on ocean-going vessels permit full use of the system with no increase in cost.

Bibliography

Defense Mapping Agency, Radio Navigational Aids, Pub. 117A, Atlantic and Mediterranean Area. Hydrographic Center, Washington, D.C., 1977.

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III. SURVEY CATEGORIES

A. Ship Control

1. Navigational Aids

b. Mechanical Navigational Aids

- Rate-of-Turn Indicator
- Autopilot
- Pitometer Log
- Gyro Compass
- Dead Reckoning Analyzer

RATE-OF-TURN INDICATORS

System Definition

Provides quantitative information regarding ship's turning motion expressed in degrees per second.

System Description

This is a self-contained solid state instrument that converts single speed 400 Hz synchro heading information from the gyrocompass into a direct current signal proportional to the rate of change of ships heading. The system is manufactured by Sperry Rand.

System Capability

Output signal can be used as a control voltage for rudder limiting and can also be used to supply visual rate of turn information to the helmsman.

System Accuracy

Can determine turn rate up to one degree per second in increments of three minutes of arc per second.

System Advantages

Gives accurate rate of turn information to helmsman as he is turning. This information is not to be confused with ship's heading information. It is precisely the time derivative of ship's heading or stated differently the angular velocity of ship.

System Disadvantages

Must obtain system imput from a gyrocompass system.

Mitigative Potential

This device gives another bit of dynamic information to the navigator and could possibly, when joined to an integrated navigation system, tell the navigator and helmsman explicitly if their steering response is rapid enough to avoid an accident.

System Costs

$500.

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Sperry Marine Systems, Worldwide Headquarters, Great Neck, New York, 11020.

AUTOPILOT

System Definition

The autopilot is an automatic steering system that senses the displacement and rate at which the ship's direction of heading departs from the command heading, for whatever reason, and automatically applies the amount of rudder necessary to return the ship to the pre-selected heading.

System Description

The Sperry Gyropilot consists of three essential components:

- Control Panel
- Helm Unit
- Signal Processor

The Control Panel contains the heading selector/repeater module, the heart of the automatic steering control system. A control is provided to synchronize the repeater when the master compass is energized initially. It features a full 360-degree repeater dial, 1-degree increments referenced to a fixed lubber line. A movable pointer, friction-coupled to the repeater dial, can be positioned up to 345 degrees in either direction to select a desired heading change. As the ship responds to the heading change order, the repeater dial and heading pointer turn together to the "heads up" (lubber line) position and the new heading is maintained automatically thereafter.

The helm unit provides full followup hand-electric control of the rudder. A steering wheel, with drag to provide "feel," operates an illuminated rudder order scale and synchros, which produce an electrical signal proportional to rudder order. Maximum rudder order is mechanically limited to $\pm 35^{\circ}$ on the standard unit.

The Signal Processor utilizing solid-state and integrated circuit components provides signal processing for the control system. The basic design includes individual plug-in modules for Power Supply, Demodulator, Rudder Order Computer, and Rudder Servoamplifier. Internal adjustments and test points are included on individual modules.

System Capability

The Sperry autopilot has the following capabilities:

- Hand-Electric steering with full followup

- Automatic heading-keeping and heading-changing with manual change of heading selection
- Emergency non-followup steering with override feature
- Computer-generated Command Heading option with Integrated Navigation System

A dual gain circuit uses a low gain and small rudder angles within a given ship's natural yaw band, thus minimizing rudder drag. This changes to high gain when the ship for some reason is forced out of the natural yaw band.

System Accuracy

Can maintain course with up to $\pm 5^{\circ}$ weather yaw.[1]

System Advantages

- Can provide steering control for a wide variety of vessels, including VLCC and ULCC tankers
- Flexible because of modular construction. Can be used in integrated navigation system
- Can be adjusted for various weather and loading conditions and also speed of rudder response. Hardover rudder response from port to starboard can take as little as four full turns of the wheel.

System Disadvantages

- Use of the system can give a false sense of confidence and allow poor watchkeeping and helmsmanship practices to ensue. Most commonly, this means that everyone can leave the bridge while the ship maintains a set course.
- Subject to electrical power failure

Mitigative Potential

The autopilot can be a definite aid in course maintenance, especially in open sea and fairway regions of the Gulf of Mexico. It would reduce course-position uncertainty and could probably be evaluated on the TSC model.

System Costs

$5,000.

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[1] Sperry Marine Systems (Great Neck, New York: Worldwide Headquarters).

PITOMETER LOG

System Definition

The Pitometer Log is an instrument used to measure the speed of a vessel through the water.

System Description

The Pitometer is known as a pitot-static log that is designed to detect both dynamic and static pressure. The pitot-static log requires the use of a rodmeter projecting through the bottom of the vessel into the water. The rodmeter contains the sensing device used to determine the speed. The rodmeter is normally retractable to prevent its being damaged in shallow water. The rodmeter is supported by a T-valve, which also provides a means for closing the hole opening when the rodmeter is withdrawn or housed. The pitometer has a remotely located indicator transmitter, which houses the electrical and electro-mechanical parts. The signal received from the pitot-static log is converted into a readout of speed, which can be transmitted by synchronous motors to display units throughout the ship. As the ship moves through the water, the forward side of the rodmeter is exposed to dynamic pressure which is proportional to the speed of the ship. The pitot tube is the device by which the difference in dynamic static pressures may be detected. The differences of the two pressures will vary with the speed of the ship. Essentially the device consists of two tubes, one inside the other. One tube opens forward and is subjected to dynamic pressure when the ship is in motion; the other opens towards the ship and is exposed only to static pressure. There are two types of speed measuring devices, which utilize the pitot-static principle. They are commonly known as the Pitometer Log and the Bendix Underwater Log.

The two pressures which are measured by the pitot-static log are led to separate bellows attached to the opposite ends of a centrally pivoted lever. This lever is electrically connected to a mechanism, which controls the speed of a pump. When the vessel is dead in the water, the pressures are equal and the pump is stopped. When the ship is moving, the pump's speed is regulated so that the pressures in the two bellows are equalized. Thus, the pump speed is proportional to the ship's speed.

System Capability

The pitometer log, while measuring the speed of the ship, also has the capability of measuring the distance the ship has traveled. This later function is

performed through the use of mechanical and electrical linkages to convert the movement of the bellows into rotary motion for the transmission to distance indicators by self-synchronous motors. The device has the capability of indicating both speed through the water and the distance covered through the water.

System Accuracy

The pitometer is a relatively accurate instrument. There are, however, various situations during which time the pitometer log may register a higher or lower speed than the ship is actually making through the water. The device becomes much less accurate in shallow water due to the potential flow problem that occurs when a vessel is in shallow water. The closeness to the bottom changes the potential flow of velocity distribution by restricting the region in which the water can flow around the hull, causing an increase in speed reading in which the water can flow around the hull, causing an increase in speed reading by a bottom mounted sensor. Additionally, the speed sensor is usually rigidly attached to and undergoes the motion of the vessel carrying it. Because of the fact that the sensor is not located at the center of gravity of the ship, additional movements which constitute six degrees of freedom permit erroneous readings to be generated by the pitometer log.

Advantages

- Pitometer log has the definite advantage of providing to the vessel operators the speed and distance that the vessel is traveling forward in the water. This permits navigational checks to be made with utilizing dead reckoning techniques and verifying when other techniques are available.

Disadvantages

- The primary disadvantage of the pitometer log is the amount of error that can be introduced when a vessel has a drift component due to the wind. The speed sensor will not measure this leeway. Most of the average motion errors are quite small, usually less than a few tenths of one percent and can be neglected. Leeway due to wind, however, may be several knots, and cannot be neglected if accurate velocity sensing is required.
- Other disadvantages occur during maneuvering of a vessel. As a vessel turns, a drift angle is developed between the heading and the actual water velocity vector at the sensor. The speed sensor only measures the

longitudinal velocity components and the speed is reduced by the cosine of the drift angle at the sensor.

- Other disadvantages to the pitometer log occur when the vessel is moving through a current that is flowing longitudinally to the vessel or when a vessel is moving with the current.

Mitigative Potential

Primary mitigative potential of the pitometer log lies in the fact that it can be utilized in conjunction with other navigational methods to determine the longitudinal movement of a vessel. In the event other navigational devices become inoperative, the pitometer log is accurate enough to permit navigation to continue in open waters or in waters which contain few, if any, hazards to navigation.

System Costs

Under $500.

Bibliography

Dutton's Navigation and Piloting, 12th Edition Annapolis, Maryland: Naval Institute Press, 1972.

Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrograhic Center, 1977.

GYRO COMPASS

System Definition

The basis for the gyrocompass is a rotating element, the gyroscope, which seeks true North. Sensors determine the position of the gyroscope, and this is displayed at remote stations by gyro repeaters.

System Description

A gyrocompass system consists of four components:

1. Master Unit--contains the gyroscopic north seeking element, gimballing, and associated electrical components and wiring. This may include a vertical seeking element as well as for the measurement of roll and pitch.

2. Control Cabinet--contains computing and amplification equipment and required controls, dials, and meters for operation of the system. The computer generates electrical signals to properly torque the gyro to compensate for vessel speed and latitude.

3. Power Supply Equipment--provides regulated electric power of the correct voltage and frequency to the gyrocompass system. Additionally, the power supply has the capability to switch the gyrocompass to a storage battery power supply in the event ship's power is interrupted.

4. Alarm Unit--a system to alert personnel when electrical power is low or interrupted or a malfunction exists in the gyrocompass system.

System Capability

The gyrocompass maintains its heading toward true North or true vertical depending upon its intended purpose. When properly compensated by the application of correct torque, its tendency to seek true North is independent of latitude, own ship speed, roll and pitch.

System Accuracy

When properly corrected, gyrocompass error should never exceed one degree. The error is determined by comparing the observed gyro bearing with the charted true bearing of a natural or artificial range, by comparing an observed gyro bearing of an object ashore from a well fixed position to the charted bearing from that position, by comparing the gyro bearing of a celestial body with the computed bearing, a "trial and error" adjustment, or comparing the gyro with another for which the error is known. Accuracy is somewhat diminished in the high latitudes.

System Advantages

- The gyrocompass seeks true North rather than magnetic North.
- It can be used near the poles where a magnetic compass is useless.
- It is not affected by magnetic material in its vicinity.
- Outputs from the system can be transmitted easily to other systems or indicators throughout the ship.

System Disadvantages

- Requires a constant source of electric power.
- Requires maintenance by well trained technicians. Shipboard repair is often impractical.
- Accuracy decreases above 75^{o} latitude.
- Requires a controlled environment for reliable operation.

Mitigative Potential

When properly adjusted and maintained, the gyrocompass will provide accurate and reliable time heading information with minimum correction as long as electrical power is maintained.

System Costs

Costs of this system is of the order of $5,000.

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Dutton's Navigation and Piloting, 12th Edition Annapolis, Maryland: Naval Institute Press, 1972.

Defense Mapping Agency, American Practical Navigator, Bowditch, Volume I, Hydrograhic Center, 1977.

DEAD RECKONING ANALYZER (DRA)

System Definition

Electro-mechanical computer that uses speed and heading information to compute distance steamed.

System Description

The ship's gyro feeds heading information into the unit and the ship's log does likewise with ship's speed. The speed is time-integrated to obtain distance. The DRA then reads out miles steamed north or south and east or west along with total distance. If the system also reads out latitude and longitude it is called a Dead Reckoning Analyzer-Indicator (DRAI).

System Capability

The system is capable of tracking the ship's course through the water. Note that this is not the same as the ship's course over the bottom, since current and tide effects are not filtered by the ship's log.

System Accuracy

The chief source of error in this system is the error in the speed log caused by not taking current into account. This can vary depending on location, season, and weather.

System Advantages

This is a simple and reliable way of estimating distance made good, and thus position.

System Disadvantages

Suffers from a variable inaccuracy due to current set and is thus not reliable in itself for position determination.

Mitigative Potential

Both DRA and DRAI are not indicated for DWP mitigative use but rather as a backup system.

System Costs

Under $1,000.

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III. SURVEY CATEGORIES

A. Ship Control

1. Navigational Aids

c. Visual and Audible Aids to Navigation

SHORT RANGE AIDS TO NAVIGATION

System Definition

The term Short Range Aids to Navigation means devices such as lighthouses, lightships, buoys, daymarks, and ranges that are non-electronic in nature.

System Description

Short Range Aids to Navigation guide the mariner when he is making a landfall, piloting near land or docking.

Buoys:

The function of buoys is to warn of some peculiar danger or obstruction, channel delineation, and aid in position determination when the buoy is shown on charts. The buoyage system of the United States is known as a lateral system of buoyage.

Features which delineate buoys are size, shape, color, number and optical-audio signal equipment. It should be remembered that characteristics that denote on which side a buoy should be passed are with reference to a ship proceeding from seaward or "returning." With regard to the DWP area in the Gulf of Mexico, returning ships proceed in a northerly and northwesterly direction.

Generally all buoys offshore are fitted with radar relectors that return a sharp radar signal.

The main types of buoys are:

- Can--cylindrical shape
- Nun--cone with apex upward
- Bell--sea motion actuated clappers, single tone
- Gong--similar to bell, multi-toned
- Whistle--wave motion causes air through the counterweight tube to blow a whistle
- Light--battery powered, red, white or green
- Combination--combination light, whistle, bell, etc.
- Special Purpose--mark swimming area, salvage area, dredging, no wake, etc.

The colors of buoys denote the following:

- Black marks the port sides of channels when returning. Pass keeping buoy to port or left.

- Red marks the starboard sides of channels when returning. Pass keeping buoy to starboard or right.
- Red and black horizontal bands mark channel "junction buoys." Black on top keep buoy to port for preferred channel when returning. Red on top keep buoy to starboard for preferred channel when returning.
- Black and white vertical stripes mark fairway or midchannel and may be passed close aboard on either side.
- White marks anchorage.
- Yellow marks quarantine area.
- White with green cap marks dredging.
- White with black horizontal stripe marks fishnet area.
- White and orange with alternate bands mark special purpose, such as restricted speed area to reduce wake.
- Yellow and black vertical stripes mark seaplane mooring.

Buoys are marked with letters and numbers, or both, for chart identification. Numbers increase from seaward and are in approximate sequence. Even numbers are on solid red buoys and odd on solid black buoys. Sometimes letters are used to abbreviate a prominent danger or obstruction. Can buoys are black and nun buoys are red. Black and white vertically-striped buoys may be either nun or can. Red lights are used on red buoys or junctions with red on top band. Green lights are used on black buoys or junction buoys with a black band on top. White lights are used on any color buoy, its distinguishing characteristics being its temporal "rhythm." Unlighted buoys are fitted with retro-reflecting materials of the same color as lights so as to permit identification by searchlights. The significance of the colors is the same as lights.

Chart information on buoys is as follows:

- Position is indicated by a colored diamond showing color of buoy with a circle showing location.
- A magenta circle indicates a lighted buoy.
- Color of light and characteristics are listed near diamond.
- Additional printed information is used to advise of warning features, such as sound and bell signals.
- Number and letter designation is given in quotation marks near the symbol for the buoy.
- C, N, or S stand for can, nun or spar, respectively.

Large navigational sea buoys possess AC-powered lights, sound signals and meteorological sensors that are remotely monitored. They have in general replaced

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DEEPWATER PORTS APPROACH/EXIT CONTROL CAPABILITIES ASSESSMENT. --ETC(U)
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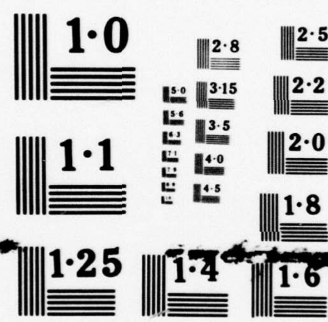

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

light ships. Their fog horns have a range of three miles and their lights a range of 14 miles when the visibility is 10 miles.

Fixed unlighted structures used as aids to navigation are called day beacons. They come in a variety of shapes, materials and colors for easy identification, the most common being green squares to port and red triangles to starboard when returning. Day beacons marking the sides of channels are colored and numbered the same as buoys and have a reflective top for night identification.

Lights:

Lights, exclusive of buoys, are used in a number of ways to aid mariners; the various types are:

- Lighthouses

Lighthouses are powerful fixed lights at prominent harbor entrances and headlands. Most are not manned and support a radio beacon and fog signal. Identification at night can be made by the light's color and rhythm. Minimal ranges (when visibility is 10 miles) for all lights maintained by the U.S. Coast Guard are listed with other distinguishing characteristics of the light and the structure in the Light List.

- Lightships and Large Navigation Buoys

Lightships and Large Navigational Buoys serve the same purpose as lighthouses. Their presence indicates that it is not practical or possible to put a fixed structure in their place.

Both are red hulled. The lightships are white in superstructure, and buff in stack and lantern tower. Signal specifics for lightships and large navigational buoys are given in Light Lists along with fog signal information and radio beacon specifications.

- Offshore Primary Light Towers

These have largely replaced lightships and serve the same function.

- *Range Lights*

Two lights separated both horizontally and vertically such that when brought in line indicate the ship is on the axis of the channel.

Some lights have colored sectors that indicate danger of grounding. The dynamic characteristics of the colored sectors will be the same as the white. Reference to the Light Lists facilitate identification.

- Sound Signals

Sound signals are of various types and are used in periods of reduced visibility. Those on lightships, large navigational buoys and lighthouses are AC-powered, 500 Hz

or 300 Hz electronic sound signals or old "two tone" compressed air devices. Air whistles and bells, both actuated by buoy motions are most common in buoys. Sound signals are located on most lighthouses, lightships, and large navigational buoys. Light Lists give location and the rated range and rhythm of the sound signal.

System Capability

The capability and characteristics of the various aids to navigation discussed here are specified in detail in two types of publications: Light Lists (a United States Coast Guard Publication covering United States and Canadian Great Lakes waters) and List of Lights (published by the United States Defense Mapping Agency Hydrographic/Topographic Center, covering foreign coasts). Corrections to Light Lists and Lists of Lights are published weekly in the Notice to Mariners.

Both lists give detailed information regarding lights of all types, radio beacons, fog signals. Light Lists also give data on lighted and unlighted buoys.

System Accuracy

Light Lists and Lists of Lights specify characteristic information on aids to navigation where applicable.

System Advantages

The various aids have evolved and improved with time and have become an integral and essential part of the navigator's tools while traversing in or near a coastal or harbor region.

System Disadvantages

None except for misuse or carelessness in identifying and locating aids or not following restrictions as to their use. The failure to identify lights properly is one of the most frequent causes of groundings. In the DWP context with a VLCC this could have disastrous consequences.

Mitigative Potential

The mitigative potential for the devices discussed herein bears principally on groundings and rammings. There is, however, an important human factor connected in the proper use of aids to navigation, which is difficult if not impossible to assess in analytical terms. Observational negligence and a false sense of security regarding the mechanical reliability of aids are two principal causes of accidents. Extinguished lights that are not yet listed in Notice to Mariners or when listed, not consulted by the navigators is a case in point, and has led to serious accidents. Misidentification of

lights is another example. Providing redundant identifying means such as racons on buoys marking fairway junctions would have significant mitigating potential.

System Costs

Costs are greatly variable and must be determined on a case by case basis.

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III. SURVEY CATEGORIES

A. Ship Control

2. Weather Aids

a. Weather Broadcasts

III. SURVEY CATEGORIES

A. Ship Control

2. Weather Aids

a. Weather Broadcasts

WEATHER BROADCASTS

System Definition

Marine weather broadcasts are transmitted by a worldwide network of government and commercial radio stations, using radiotelegraph, radiotelephone, radioteletype and radiofacsimile.

System Description

In 1878, the International Meteorological Organization (IMO) was organized to facilitate worldwide cooperation in weather research and reporting. In 1951, the functions and assets of IMO were transferred to the World Meteorological Organization (WMO), a specialized agency of the United Nations. The WMO, which has a membership of 145 countries and territories has the following purposes:

- To facilitate worldwide cooperation in the establishment of networks of stations for making meteorological and hydrological observations or other geophysical observations;
- To promote the establishment and maintenance of meteorological services;
- To promote the establishment and maintenance of systems for the rapid exchange of weather information;
- To promote standardization of meteorological observations and ensure the uniform publication of observations and statistics;
- To further the application of meteorology to aviation, shipping, hydrology, agriculture, and other human activities; and
- To encourage research and training in meteorology and to assist in coordinating the international aspects of such research and training.

As a result of the efforts of IMO and its sucessor WMO, there exists today a worldwide coordinated network of government and commercial radio stations, which broadcast weather reports of the important water areas of the world, using a variety of emissions which permit the mariner to have access to timely and accurate weather forecasts which are vital to safe navigation. In the United States this program is administered by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration, Department of Commerce. Through Agreements, NWS provides the weather reports to selected government and commercial radio stations for dissemination to the public.

System Capability

In the Gulf of Mexico, the Caribbean Sea and approaches, the following stations transmit weather relating to these areas:

Radiotelegraphy

Station	Times (GMT)	Frequency (kHz)	Type of Broadcast*
Norfolk, Virginia (NAM)			
Area: North Atlantic north of 03^{o} N, west of 35^{o} W, including Caribbean Sea and Gulf of Mexico			
	0030, 1230	8090 12135 16180 20225*	W, A
	0630, 1230	do.	W, F

* 1200 to 0000 only.

Station	Times (GMT)	Frequency (kHz)	Type of Broadcast*
Amagansett, New York (WSL)			
Area: West Central North Atlantic; New England waters; Southwest North Atlantic; E. Caribbean Sea.			
	0500, 1100 1700, 2300	418 8514	F
Miami, Florida (NMA)			
Area: Southwest North Atlantic, Jupiter Inlet to Dry Tortugas and coastal waters including Straits of Florida.			
	0100, 1600	440	F, G
	On receipt, preceded by an announcement on 500 kHz.	440	W
Key West, Florida (NAR)			
Area: Western North Atlantic west of 35^{o} W, including Caribbean Sea and Gulf of Mexico.			
	0300, 1200	5870 25590 (day only)	W, A
	0630, 1900	do	W, F

*See new section below entitled "Weather Message Content" for definition.

Station	Times (GMT)	Frequency (kHz)	Type of Broadcast

Mobile, Alabama (WLO)

Area: Gulf of Mexico, Caribbean Sea; West Central North Atlantic.

	1300, 1700, 2300	438 6466 8474.5 12704.5 17172.4	F

New Orleans, Louisiana (NMG)

Area: Gulf of Mexico; Caribbean Sea.

	0020, 1720	428	F
	on receipt, odd H+18 and H+48 preceded by announcement on 500 kHz	428	W

New Orleans, Louisiana (WNU)

Area: Gulf of Mexico, Caribbean Sea.

	0430, 1630	478 2048 4310* 6495 8570 12826.5** 17117.5 22431**	F

Galveston, Texas (KLC)

Area: Gulf of Mexico; Western Caribbean Sea; coastal waters, Biloxi, Mississippi, to Port O'Connor, Texas.

	0530, 1130 1730, 2330	484 4256* 6369 8666 13038.* 17208.8*	F
	on receipt and odd HO30	do	W

* Night only
** Day only

Station	Times (GMT)	Frequency (kHz)	Type of Broadcast

San Juan, Puerto Rico (NMR)

Area: Eastern Caribbean Sea; Puerto Rico, and Virgin Islands coastal waters.

	0120, 1620	466	F
	on receipt, H+18 and H+48	466	W

Radiotelephony

Fort Collins, Colorado (WWV)

Area: North Atlantic waters north of 3° N, west of 35° W, including Gulf of Mexico and Caribbean Sea.

	H008, H009	2500 (6A3)	S, W
		5000 (6A3)	
		10,000 (6A3)	
		15,000 (6A3)	

Portsmouth, Virginia (NMN)

Area: (a) North Atlantic north of 03° N, west of 35° W, including Gulf of Mexico and Caribbean; (b) New England Waters; (c) West Central North Atlantic Waters; and (d) offshore waters Southwest North Atlantic.

	0400	4393.4 (3A3J)	S, F*
		6521.8 (3A3J)	
		8760.8 (3A3J)	
	0530	do	S, F**
	1000	do	S, F***
	1130, 2330	6521.8 (3A3J)	S, F**
		8760.8 (3A3J)	
		13144 (3A3J)	
	1600, 2200	do	G, S, F***
	1730	8760.8 (3A3J)	S, F**
		13144 (3A3J)	
		17290 (3A3J)	

* For areas c and d
** For area a
*** For areas b, c, and d

Station	Times (GMT)	Frequency (kHz)	Type of Broadcast

Miami, Florida (WOM)

Area: Caribbean Sea, Southwestern North Atlantic, Gulf of Mexico.

	0430, 1230	4428.6 (3A3J)	F
		8792.8 (3A3J)	
		13137 (3A3J)	
		17325 (3A3J)	
		22688.5 (3A3J)	
	0530, 1130	4422.2 (3A3J)	F
		8796 (3A3J)	
		13140.5 (3A3J)	
		17286.5 (3A3J)	
		22692.00 (3A3J)	

Miami Beach, Florida (NCF)

Area: (a) Coastal waters Jupiter Inlet, Florida, to Dry Tortugas, including Straits of Florida; (b) offshore waters, Southwest North Atlantic.

	0350, 1550	2670 (3A3J)	F
	1130, 1730	157.1 MHz (36F3)	F*
	2230, 1330		
	On receipt	2670 (3A3J)	W
		157.1 MHz (36F3)	

* For area a.

Key West, Florida (NOK)

Area: Coastal waters Jupiter Inlet to Dry Tortugas, including Straits of Florida; Cape Sable to Tarpon Springs, including Florida Bay

	1100, 1700	157.1 MHz (36F3)	F
	2200		

Mobile, Alabama (WLO)

Area: (a) Offshore waters Gulf of Mexico; Caribbean Sea; southwestern North Atlantic; (b) Coastal waters, Straits of Florida to Brownsville, Texas.

	0500, 1100	2572 (3A3H)	F
	1700, 2300	162.00 MHz (36F3)	
		161.90 MHz (36F3)	
	On receipt	do	

New Orleans, Louisiana (NMG)

Area: (a) Offshore waters, middle Gulf of Mexico; (b) Coastal waters, Biloxi, Mississippi, to Port Arthur, Texas

	1030, 1230,	2670 (3A3J)	F
	1630, 2230		
	1050, 1650,	157.1 MHz (36F3)	F
	2250		
	On receipt	2670 (3A3J)	W

Station	Times (GMT)	Frequency (kHz)	Type of Broadcast

New Orleans, Louisiana (WAK)

Area: (a) Offshore waters, Gulf of Mexico, Caribbean Sea; (b) Coastal waters, Apalachicola, Florida, to Port Arthur, Texas.

	0500*, 1400*	2482 (3A3H) 2598 (3A3H) 4419 (3A3H)	F
	On receipt and on odd H.	do	W

* One hour earlier during daylight saving time.

Galveston, Texas (NOY)

Area: (a) Offshore waters, middle and Western Gulf of Mexico; (b) Coastal waters, Morgan City, Louisiana, to Brownsville, Texas.

	1050, 1250, 1650, 2250	2670 (3A3J)	F
	On receipt	2670 (3A3J)	W

Galveston, Texas (KOP)

Area: (a) Offshore waters, middle and Western Gulf of Mexico; (b) Coastal waters, Morgan City, Louisiana, to Brownsville, Texas.

	0600*, 1800*	2450 (3A3H) 2530 (3A3H)	F
	On receipt and odd H015	do	W

* One hour earlier during daylight saving time.

Corpus Christi, Texas (KCC)

Area: Western Caribbean Sea; Gulf of Mexico; Coastal waters, Morgan City, Louisiana, to Brownsville, Texas.

	0000, 1200	2538 (3A3H)	F
	On receipt	2538 (3A3H)	W

Port Isabel, Texas (NCH)

Area: (a) Western Gulf of Mexico; (b) Coastal waters, Port O'Connor, Texas, to Brownsville, Texas.

	1040*, 1240,* 1640, 2240	2670 (3A3J)	F*
	1035, 1635, 2235	157.1 (36F3)	F**
	On receipt	2670 (3A3J)	W

* For area a and b
** For area b

Station	Times (GMT)	Frequency (kHz)	Type of Broadcast

Swan Island (WSG)

Area: Eastern Gulf of Mexico and Western Caribbean Sea.

	1705 and On request	2738 (6A3)	F, LR*

*Swan Island report.

San Juan, Puerto Rico (NMR)

Area: Eastern Caribbean Sea, including Puerto Rico, Virgin Islands, and adjacent waters.

	0305, 1505	2670 (3A3J)	F
	On receipt	2670 (3A3J)	W
	1110, 1710, 2210	157.1 MHz (36F3)	F

Radio Facsimile

Station	Times (GMT)	Carrier Frequency (kHz) and Emission (hours of use in parentheses)	Type of Broadcast

Brentwood, New York (WFH/WFK)

Area: Western North Atlantic (transmission beamed toward Caribbean, Central and South America on a mean bearing of 165° T).

		9290 F4 (0712-1212) 9389.5 F4 (0712-1212) 11035 F4 (0712-1212) 17436.5 F4 (1950-2350)	
	0750, 1950		Surface analysis
	1046, 2307		24-hour surface/sea and wind prognosis.
	1150		36-hour wind wave/swell prognosis; 24-hour/36-hour combined sea height prognosis.

Station	Times (GMT)	Carrier Frequency (kHz) and Emission (hours of use in parentheses)	Type of Broadcast
Norfolk, Virginia (NAM)			
Area: North Atlantic Ocean (United States Navy Fleet Broadcast).			
		3357 F4 4975 F4 8080 F4 10865 F4 16410 F4 20015 F4	
	0000		Schedule
	1200		Test Chart

Station	Times (GMT)	Carrier Frequency (kHz) and Emission (All F4)	Type of Broadcast
Washington, D.C. (KWAF)			
Area: North Atlantic Ocean.			
		4793.5 6912.5 10185 12201 13472.5 14671.5 15620.5 17670.5 19955 23068.5	

(Two frequencies are chosen each day depending upon the propagation conditions.)

	0636,1836		Surface analysis.
	0700, 1900		12/24-hour surface and significant weather prognosis.
	1200		30-hour surface prognosis.
	0336, 0900, 1545, 2000		Weather advisory
	0530		Extended forecast (Monday, Wednesday, Friday).
	0500, 0515, 1708, 1730		Test Chart

Radioteletype

Station	Times (GMT)	Carrier Frequency (kHz) and Emission (All F9)	Type of Broadcast
New York, New York (KJFK) Area: North Atlantic			
		Night: 4055, 8130 Day: 12180, 16220, 16280, 23211	
	0537, 1137, 1737, 2337		Surface analysis for North Atlantic 10°-80° N; 35°-100° W.
	0020, 1220		30-hour surface prognosis for 20°-90° N; 25°-155° W.
Miami, Florida (WBR) Area: Broadcast point to 40° S, 30°-105° W.			
		4061.5, 8140 13624, 18765	
	0500, 1100, 1700, 2300		Surface weather map for United States, South Canada, and coastal areas of Atlantic.
	0515, 1715		36-hour forecast for Eastern Caribbean.
	0630, 1830		Tropical analysis; discussion for equator 30° N; 50°-110° W. Geographical coordinates in form Q La La Lo Lo.
	0845		48-hour surface prognosis for 20°-60° N; 50°-145° W.
Mobile, Alabama (WLO) Area: Southwest North Atlantic, Caribbean Sea, and Gulf of Mexico.			
	0020, 1120, 1720	8714.5	Forecast and Warnings.

Continuous VHF-FM Weather Broadcasts

In addition to the above weather broadcasts, the National Weather Service provides continuous weather broadcasts to mariners within range of its 77 VHF-FM radio stations in coastal locations. These stations transmit on two basic frequencies, 162.40 and 162.55 MHz (36F3 emission), which can be received up to 40 miles from the antenna site depending upon terrain and type of receiver. These voice broadcasts are taped and are repeated every 4 to 6 minutes. The tapes are updated periodically, usually every 2 to 3 hours, and amended as required to include the latest information.

Broadcasts give local and area warnings and forecasts, radar summaries, observations, sea conditions, and harbor water levels where available. When severe weather warnings are issued, routine transmissions are interrupted. For specific information concerning stations and frequencies, consult the latest edition of Worldwide Marine Weather Broadcasts, National Weather Service. United States Government Printing Office: Washington, D.C.

Other Weather Broadcasts

Other stations in addition to those described above broadcast weather for the Gulf of Mexico, Caribbean Sea and approaches. The stations listed were selected for completeness of coverage of the deepwater port area and its approaches, for further details consult the latest edition of Worldwide Marine Weather Broadcasts.

Explanation of Symbols Used

Above Emissions

0.1A1	Amplitude modulated telegraphy with 0.1 kHz bandwidth.
6A3	Amplitude modulated telephony with a 6 kHz bandwidth.
3A3A	Amplitude modulated telephony single sideband reduced carrier with a 3 kHz bandwidth.
3A3H	Amplitude modulated telephony single sideband with a full carrier, and a 3 kHz bandwidth.
3A3J	Amplitude modulated telephony single sideband with a suppressed carrier, and a 3 kHz bandwidth.
36F3	Frequency modulated telephony with a 36 kHz bandwidth.
F4	Frequency modulated radio facsimile.
F9	Frequency modulated radioteletype.

Weather Message Content

A	Analysis--coded weather chart that shows pressure patterns and frontal systems over an area at a specified time.
F	Forecast--a statement describing weather and/or sea conditions expected in an area for a specified period of time in the future. (Usually 24 to 36 hours.)

LR Synoptic Reports--weather reports from land stations or ships.

P Prognosis--coded weather chart that shows the expected pressure pattern for an area at a specified future time.

S Synopsis--a verbal description of the most recent weather chart for an area, that is, location and central pressure of high and low pressure centers, direction and speed of their movement, frontal systems, etc.

W Warnings--gale, storm, or hurricane/typhoon warnings. Warning categories are: Small Craft Advisory (used in United States only); Gale Warnings, Storm Warnings, and Hurricane Warnings.

G Gulf Stream Analysis--gives location and strength of major axis and other data relating to the Gulf Stream.

System Accuracy

Not applicable.

System Advantages

- Permits vessels to take evasive and other action to either avoid bad weather or minimize its effect
- Permits vessels to take advantage of favorable winds and currents.

System Disdvantages

- Improved weather reporting requires as many local weather reports as possible, vessels should therefore send these reports or a regular basis when at sea.

Mitigative Potential

Since the Gulf of Mexico is an area subject to hurricances, a comprehensive weather broadcasting system can permit vessels not only to avoid these dangerous storms, but also use favorable winds and currents.

System Costs

Since a radio receiver already installed can be used to copy many types of broadcasts, costs of the weather service should be minimal.

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III. SURVEY CATEGORIES

A. Ship Control

3. Maneuvering Aids

a. Auxiliary Steering Gear

b. Bottom Clearance

c. Bow Thrusters

AUXILIARY STEERING GEAR

System Definition

Auxiliary steering gear is an alternate means of steering independent of the main steering gear.

System Description

Coast Guard regulations require all United States certificated vessels be equipped with auxiliary steering gear independent of the main steering gear and of adequate strength and capacity to steer the vessel at navigable speed. Additionally, it shall be capable of being activated rapidly in an emergency.

Power driven auxiliary steering gear is capable of moving the rudder from 15^{o} on one side to 15^{o} on the other in a time interval of 60 seconds, with the vessel operating at half speed or 7 knots, whichever is greater.

An alternative steering station is required to be located on the after weather deck unless two separate and independent steering control systems are provided in the pilothouse. Communications for transmitting orders and a rudder angle indicator shall be provided at an alternative station.

System Capability

At the International Conference on Tanker Safety and Pollution Prevention held by IMCO in February 1978 improved emergency steering standards were adopted. The Conference approved the following improvements to steering gear standards for tankers of 10,000 gross tons and upwards:

For new and existing tankers:

1. Two remote steering gear control systems operable from the navigating bridge. In the event of failure of the remote steering gear control system in operation, the other system shall be capable of being brought into immediate operation from a position on the navigating bridge.
2. Control of the main steering gear shall also be provided in the steering gear compartment.
3. Means shall be provided in the steering gear compartment to disconnect the remote steering gear control system from the power circuit.
4. A means of communication shall be provided between the navigating bridge and the steering gear compartment.
5. The exact angular position of the rudder shall be indicated on the navigating bridge. The rudder angle indication shall be independent of the remote steering gear control system.

6. The angular position of the rudder shall be recognizable in the steering gear compartment.

For new tankers:

1. The main steering gear shall comprise two or more identical units.
2. The main steering gear power units shall be arranged to start automatically when power is restored after a power failure.
3. In the event of failure of any of the steering gear power units an alarm shall be given on the navigating bridge. Every steering gear power unit shall be capable of being brought into operation either automatically or manually from a position on the navigating bridge.
4. An alternative power supply, at least sufficient to supply a steering gear power unit so as to enable it to move the rudder at a specified rate and also to supply its associated remote steering gear control system and the rudder angle indicator, shall be provided.

The Conference approved additions to SOLAS 74, Chapter V, which include the following:

1. Testing of manual steering gear after prolonged use of the automatic pilot and before entering areas where navigation demands special caution.
2. Where navigation demands special caution, ships shall have more than one steering gear power unit in operation when such units are capable of simultaneous operation.
3. Checks and tests to be conducted within 12 hours before departure.
4. Certain emergency steering drills to be conducted at least once every three months.

Mitigative Potential

When ratified by sufficient IMCO member countries and placed into effect, the new IMCO standards for improved emergency steering should reduce the probability of collisions, rammings and groundings of vessels caused by steering failure. A reduction of accidents of this nature would reduce oil pollution, property damage and personal injuries and deaths.

System Costs

The cost of a back-up steering gear system with failure alarm has been estimated to be approximately $10,000 per vessel. This figure appears low if the IMCO standard for an automatically activated alternate power source is required.

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BOTTOM CLEARANCE

System Definition

Bottom clearance is the depth of water between the bottom of the vessel and the floor of the channel or other body of water.

System Description and Capability

Experience has shown that vessels navigating with very small bottom clearances are quite slow to respond to rudder and engine orders. This was also shown in a technical report on Vessel Maneuvering Simulation, H. Eda of Stevens Institute of Technology carried out for the Coast Guard.

There is no required bottom clearance established in United States waters. As a result, some vessels enter port touching the bottom. Due to the slow reaction time for vessel maneuvers in this condition, the probabilities for casualties increase. This is not a favorable situation for any vessel, let alone those carrying hazardous cargoes.

The Permanent International Association of Navigation Congresses (PIANC) in 1974 recommended there be at least 1 meter of bottom clearance for larger vessels. Several countries have established or adopted bottom clearances for ports. Finland has adopted a figure of 0.6 meters for their ports. Europort authorities require a bottom clearance of 10 percent of draft inside the jetties and 5 percent in the immediate terminal areas.

In the United States, many site studies for LNG facilities prepared for the Federal Energy Regulatory Commission recommend the depth of water in the approach channel and at the berth to be the draft of the vessel plus 10 percent. Some studies recommend greater depth in areas subject to heavy tidal action and in areas with rocky bottoms.

Regulations for Deep Water Ports provide that no tanker may operate, anchor, or be moored in any area of the Traffic Separation Scheme, Safety Zone, or anchorage area in which the net bottom clearance of the tanker would be less than 5 feet.

Mitigative Potential

From studies and discussions, it seems apparent a required bottom clearance should be adopted to increase the maneuverability of large vessels in ports. Any increase in maneuverability realized would reduce the probabilities for accidents.

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BOW THRUSTERS

System Definition

A bow thruster is a propeller in a transverse tunnel open to the sea in the bow of the vessel.

System Description

The system is composed of a propeller placed in a thwartship tunnel below the waterline, a diesel drive unit and associated controls.

The system does not affect a vessel's dimensions, cargo carrying capacity or clean ballast capacity. It will cause a nominal change in fuel consumption and ship's speed.

System Capability

The system can exert lateral forces in either direction thereby improving ship control at low speeds and presumably avoiding spill causing casualties.

System Advantages

- Improved maneuverability at low speeds.
- More effective than twin screws for turning ability at low speeds.

System Disadvantages

- Lack of overall effectiveness in reducing marine casualties, which result in spillage.
- Need for additional ship handling training for effective use of thrusters.

Mitigative Potential

Bow thrusters are effective in improving vessel maneuvering characteristics only at low speeds. This improvement could assist in reducing rammings around berths and piers. However, at low speeds, spillage by rammings would have a very low or negligible occurrence. The Coast Guard has stated that only six percent of all collisions, rammings and groundings, are caused by inadequate vessel maneuvering capabilities.

System Costs

The cost for a 1500 HP diesel driven thruster would be approximately $400,000.

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III. SURVEY CATEGORIES

A. Ship Control

4. Advisory Procedures

a. Vessel Traffic Separation Scheme

b. Vessel Traffic Services

VESSEL TRAFFIC SEPARATION SCHEMES

System Definition

Vessel traffic separation schemes are sea areas in which recommended lanes or zones have been established to effect the separation of opposing vessel traffic or avoid dangers in order to reduce the danger of collisions and strandings.

System Description

The International Regulations for Preventing Collisions at Sea 1972, established a new provision, Rule 1 (d), which permitted the adoption of vessel traffic schemes by the Inter-Governmental Maritime Consultative Organization (IMCO). IMCO Resolution A.284 (VIII) adopted on November 20, 1973, published standards for the establishment of vessel traffic separation schemes and also recommended some specific schemes worldwide.

Routing systems are a series of measures, which can be applied to vessel traffic routes to reduce the risk of casualties. These measures include traffic separation schemes, two-way routes, tracks, areas to be avoided, inshore traffic zones, and deep water routes. Governments may establish routing systems within their territorial waters, however, if any part of the system lies within international waters, IMCO should be consulted so that such system may be adopted by IMCO for international use. A government may establish or adjust a routing system lying partly within international waters before consulting with IMCO, where local conditions require that early action be taken, with a view toward later adoption by IMCO. When proposing or establishing a traffic separation scheme, a government should take into consideration the availability of aids to navigation appropriate to the class of vessel for which the scheme is intended. Standard chart symbols for the various types of routing system have also been adopted by IMCO.

System Capability

Routing systems were designed to separate opposing vessel traffic or avoid dangers, and therefore are capable of reducing the risk of collisions and strandings when established according to IMCO standards.

System Accuracy

When established with due regard for the availability of aids to navigation appropriate to the class of vessel for which the scheme is intended, the system accuracy should be adequate.

System Advantages

- Acts to reduce the risk of collisions or strandings
- Provided IMCO standards are adhered to, are relatively easy to establish, unless territorial sea of more than one nation is involved.

System Disadvantages

- Where territorial waters of more than one nation are involved, final agreement of the appropriate routing system may be complicated and time-consuming.

Mitigative Potential

May have some applicability in the Straits of Florida where there are several vessel traffic junction points, notably to the north and east of Miami, and southwest of Dry Tortugas. In a significant portion of the Straits of Florida a de facto traffic separation scheme is in existence, due to the seeking or avoidance of the Gulf Stream by vessels, depending upon their direction of transit of the Straits.

System Costs

Difficult to assess, but thought to be moderate.

Bibliography

Inter-Governmental Maritime Consultative Organization Resolution A. 284 (VIII) dated December 19, 1973, adopted November 20, 1973.

VESSEL TRAFFIC SERVICES

System Definition

An integrated system encompassing the varieties of technologies, equipment, and people employed to coordinate vessel movements in or approaching a port or waterway.

System Description

Background

Vessel traffic control until recently was mainly passive in nature. Controls were subtle, and were intended mostly as guidelines for the vessel master in the form, for example, of: buoys, lighthouses, radio beacons and navigation regulations. Some direct vessel traffic control did exist in the United States as early as 1902, however, when the United States Revenue Cutter Service, the forerunner of the Coast Guard, was authorized to control traffic in the St. Mary's River connecting Lake Huron and Lake Superior. Nine other limited areas in the United States had varying degres of traffic control by means of harbor radar in Los Angeles/Long Beach; traffic lights at New Orleans, the Cape Cod, and Chesapeake and Delaware Canals; communications, on the St. Lawrence Seaway and at Baltimore and Portland, Oregon; and a signal tower at Honolulu, Hawaii.

In the past, the main purpose of vessel traffic control was to reduce groundings and collisions because of their economic loss and hazard to human life. Today, as a result of massive oil spills such as those from the Torrey Canyon, the Ocean Eagle, the Argo Merchant, and the Amoco Cadiz, we have further reason for vessel control, protecting our ports, waterways and marine life from ecological damage.

Recognizing the need for a uniform system of vessel traffic control in the United States, Congress enacted the Ports and Waterways Safety Act of 1972, which gave the United States Coast Guard broad authority to control vessel traffic in United States ports and waterways. During hearings on this legislation, concern was expressed with the broad vessel traffic control powers given to the Coast Guard. In response to this, the Commandant, United States Coast Guard, testified that the Coast Guard did not plan to institute vessel traffic systems everywhere over the navigable waters, but only in areas with congested traffic, poor visibility, and high accident rates. He further stated there were many degrees of traffic control which

could be employed, such as by simple regulation, for example, by establishing one-way channels, or speed limits. Direct control would only be exercised in cases of extreme emergency.

Description

A vessel traffic control system is comprised of the following elements:

- Traffic Separation Scheme (TSS)--A scheme which aims at reducing the risk of collision in congested and/or converging areas by separating traffic. Audible/visual aid systems, techniques, charted areas, zones and lanes are combined to provide an organized flow of vessel traffic into, out of and within a port or waterway.
- Vessel Movement Reporting System (VMRS)--A communications network linking the vessels in a vessel traffic system with the vessel traffic center.
- Basic Surveillance--Visually monitoring vessel traffic movement in a port or waterway by means of basic radar and/or visual observations.
- Advanced Surveillance--Visually monitoring vessel traffic movement in a port or waterway by means of improved radar equipment, low light level TV or other advanced surveillance systems.
- Automated Advanced Surveillance Systems--Visually monitoring vessel traffic movements in a port or waterway by means of advanced surveillance aided by computers for automated traffic analysis and management.

There are different degrees of traffic management depending upon the complexity of the vessel traffic to be controlled:

- Passive Management--Coordinating vessel traffic through indirect control of vessel movements by means of traffic separation schemes. This type of management does not include manned traffic centers, but will include regulations defining the scheme and the degree of participation.
- Advisory Management--Coordinating vessel traffic by disseminating advice in the form of navigational, weather and vessel movement information. This type of management requires manned traffic centers and includes necessary regulations.
- Active Management--Coordinating vessel traffic through direct or positive control of vessel movement from a vessel traffic center.

System Capability

Vessel Traffic Systems are presently in operation in the following ports:

Port	Participation Mandatory	TSS	VMRS	AVMRS	CCTV	Radar
San Francisco	No	X	X			X
Puget Sound	Yes	X	X			X
Houston	No		X	X	X	X
New Orleans	No			X		
Valdez	Yes	X	X			X
New York	No	X	X			X
Berwick Bay	No		X			

TSS--Traffic Separation Scheme

VMRS--Vessel Movement Reporting System

AVMRS--Automated Vessel Movement Reporting System

CCTV--Closed Circuit Television

System Accuracy

Traffic systems are as accurate as the radar system used onboard ship. See section on RADAR.

System Advantages

- Reduces risk of collisions and groundings.
- Expedites the movement of vessel traffic.
- Increases navigational information made available to the mariner.
- Permits enforcement of navigation rules.
- Assists in search and rescue and emergency cases.

System Disadvantages

- Range of VTS too small to be effective over a large geographical area as encountered in deepwater ports.
- Sometimes relieves vessel master of some of his flexibility in vessel operations.
- In some instances makes Coast Guard liable to claims for damage or loss due to negligent or inefficient operation.

Mitigative Potential

Substantial when instituted selectively based on demonstrated need.

System Costs

Installation costs for San Francisco $5.8M. Annual operating costs not known. San Francisco is the most sophisticated and cost may not reflect the cost of installation elsewhere, since substantial R&D money is included.

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III. SURVEY CATEGORIES

B. Pollution Control

1. Construction Techniques

a. Double bottom

b. Double hull

c. Flue Gas Inerting System

d. Segregated Ballast

e. Crude Oil Washing (COW)

DOUBLE BOTTOMS

System Definition

A double bottom consists of ballast tanks placed on the bottom of the vessel to provide protection from grounding.

System Description and Capability

The concept of double bottoms has been discussed nationally and internationally for many years. Vessels and barges have been constructed with double bottoms, but there is no U.S. requirement to have them so constructed.

A mandatory requirement for double bottoms was advocated by the U.S. in the International Conference on Tanker Safety and Pollution Prevention held by IMCO in London, England, 6 through 17 February 1978. An overwhelming majority of other delegations disagreed. The U.S. delegation then "supported development of the concept of protective location of segregated ballast tanks as an alternative to double bottoms."

The new rules on protective location of segregated ballast tanks adopted by the Conference together with existing requirements for hypothetical oil outflow and limitations on size and arrangement of cargo tanks, will provide designers, builders and owners with the option to use double bottoms, double sides or alternative wing tank designs. These new rules, however, will not go into effect internationally until ratified by sufficient IMCO member countries.

The Coast Guard has issued a notice of proposed rulemaking regarding double bottoms in the Federal Register dated Monday, May 16, 1977. This notice proposes that all tank vessels of 20,000 DWT and over contracted for after December 31, 1979, or delivered after December 31, 1981, must have a double bottom or have pollution protection against groundings equivalent to double bottoms, and approved by the Coast Guard. This proposal is still under consideration. This proposal stipulates the double bottom shall not carry oil and that it is at least the molded breadth divided by fifteen, or two meters in height, whichever is less.

System Advantages

- Provides some pollution protection from grounding damages.

System Disadvantages

- Loss of buoyancy when empty double bottoms are penetrated causing increased difficulties in salvage.

- Increased potential of fire or explosion from cargo leaks or trapped vapors.
- Increased hazard on personnel entering double bottoms for maintenance due to trapped vapors.
- Increased cost of construction.
- Loss of cargo carrying space.

Mitigative Potential

The main reason for double bottoms is to reduce the potential of an oil spill due to grounding. If the grounding is not severe enough to penetrate the bottom, the double bottoms would have served no purpose. Additionally, if the grounding is so severe as to penetrate both the shell plating and the inner bottom the double bottom also may not have served its purpose, but may possibly reduce the oil outflow. Double bottoms will also not be effective where the grounding is so severe the vessels break up due to weather. This leaves only the situation where just the bottom plating is penetrated. In this situation there will be no oil outflow but there may be an increased difficulty in salvage operations.

Costs

In 1977 MarAd estimated the costs of installing double bottoms on a new vessel of 225,000 DWT to be $18,000,000 including construction, materials, loss of cargo space and delay in construction.

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DOUBLE HULL

System Definition

A double hull vessel has ballast tanks on the sides and bottoms of all cargo tanks.

System Description

All bulk chemical and liquefied flammable gas carriers, both vessel and barge, are required by United States regulations to be fitted with double hulls. Double hulls on oil tankers are not required.

There has been much discussion on various construction concepts, including double hulls, double bottoms, segregated ballast, etc., over the past several years. The discussions have centered on effectiveness, safety, salvage and costs. A double hull would probably be effective in reducing pollution from many groundings and collisions. In the case of severe groundings and collisions, it is alleged double hulls would assist in survivability, containment and provide additional time for response. The cargo tanks in a double hull vessel have smooth sides and bottoms allowing more cargo to be discharged. The smooth walls and bottoms also assist in cleaning tanks.

With regard to safety of double hulls, there is concern the accumulation of flammable vapors in the void spaces between the hull and cargo tanks will introduce the danger of explosion. If a double hulled vessel is punctured, water will fill the void space causing a loss of the buoyancy and stability built into the vessel, thus placing the vessel in an unsafe condition.

The loss of buoyancy resulting from a puncture of the outer shell will also cause additional salvage problems. With water filling a void space the vessel sinks lower in the water or more heavily on the bottom. If a vessel is holed by a rock pinnacle the added weight of the water and loss of buoyancy conceivably could lower the vessel sufficiently so the inner bottom is also penetrated.

The additional costs for a double hull vessel not only include the extra steel and additional work, but also the loss of revenue carrying capacity.

System Advantages

- Reduces pollution of the sea resulting from collisions, groundings and rammings.
- Cleaning of tanks is easier and less time consuming due to the smooth walls.

System Disadvantages

- Reduces the amount of cargo carried in tankers.
- Increases the costs of construction.
- Loss of buoyancy when void spaces are penetrated causing increased difficulties in salvage.
- Increased potential of fire or explosion from cargo leaks or trapped vapors.
- Increased hazard on personnel entering void spaces due to trapped vapors.

Mitigative Potential

The main reason for requiring double hulls on tankers is to reduce the potential of an oil spill due to collisions, rammings, and groundings.

System Costs

In 1977 MarAD estimated the costs for double hull construction for a new vessel of 225,000 DWT to be $28,000,000.

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FLUE GAS INERTING SYSTEM

System Definition

An inert gas system is a system which substitutes the atmosphere in a cargo tank with an inert gas to eliminate the possibility of ignition of vapors.

System Description

A flue gas inerting system comprises an electric driven fan, wet type gas scrubber, a water seal and ancillary equipment. The electric fan draws flue gas from the boiler uptakes and discharges it through the scrubber and water seal to the cargo tanks. A scrubber cools the gas and removes solids and sulphur combustion products. Oxygen content of the inert gas shall not exceed five percent by volume. The water seal removes water from the gas before it enters the cargo tank.

Instrumentation is provided to monitor the complete operation. The pressure and oxygen content of the inert gas is continually monitored on the discharge side of the fan. Alarms and automatic shutdown controls are provided when predetermined limits are attained.

The Coast Guard has issued a notice of proposed rulemaking regarding inert gas systems in the Federal Register dated Monday, May 16, 1977. This notice proposes the installation of an inert gas system in all United States flag tank vessels of 20,000 DWT and over certified to carry Grades A, B, C and D liquids and all foreign flag tank vessels in the trade of carrying flammable or combustible liquids to or from United States ports. This proposal is still under consideration.

System Capability

The system shall be capable of delivering a sufficient volume of gas to render all cargo tanks inert during loading, unloading and washing. The system shall be able to deliver at least 125 percent of the maximum rated capacity of the cargo pumps with a positive pressure being maintained at the tanks.

System Advantages

- Increased safety from fire or explosion in a cargo tank carrying petroleum or other hazardous cargoes.
- Capability of washing tanks in an inert atmosphere.
- Purging and inerting cargo tanks after discharge of cargo.

System Disadvantages

- System presently required only on United States tankships of 100,000 DWT and over and combination carriers of 50,000 DWT and over.
- Could cause asphyxiation to crew members in confined spaces should a leak occur.

Mitigative Potential

An installed, properly operating and used inert gas system should reduce or virtually eliminate fire and explosions in cargo tanks during loading, unloading and washing.

System Costs

In 1977 MarAd estimated the cost of installing an inert gas system on a vessel of 225,000 DWT to be $2,600,000.

Bibliography

- Title 46 CFR Subpart 32.53.
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SEGREGATED BALLAST

System Definition

Segregated ballast is the ballast water introduced into a tank that is completely separated from the cargo oil and oil fuel system and that is permanently allocated to the carriage of ballast.

System Description and Capability

Coast Guard regulations require all new United States vessels and all foreign vessels carrying oil and entering the navigable waters of the United States that are 70,000 DWT and above to be provided with segregated ballast tanks.

The capacity of the segregated ballast tanks shall be such that the vessel may operate safely on ballast voyages without having to use the cargo tanks for water ballast. The only exception to this is in those cases where the weather is so severe that, in the opinion of the Master, it is necessary to carry additional ballast water in oil tanks for the safety of the ship.

At an IMCO conference held in February 1978, a convention was agreed upon which will, when the convention is ratified, require all new tankers of 20,000 DWT and over to be fitted with segregated ballast tanks. In addition, a concept of protective location of segregated ballast tanks was agreed upon as an alternative to double bottoms.

The new constraints on protective location of segregated ballast tanks, coupled with the existing requirements for hypothetical oil outflow and limitations on size and arrangement of cargo tanks, will permit the use of double bottoms, double sides or alternate wing tank designs.

System Advantages

- Reduces pollution of the sea due to tank cleaning.
- Reduces requirement for tank cleaning on ballast voyage.
- Reduces pollution of the sea resulting from collisions, rammings and groundings.
- The new rules will permit flexibility of vessel design while maintaining a reduction of pollution of the sea.

System Disadvantages

- Reduces the amount of cargo carried in tankers.
- Increases costs of vessel construction.

- The new rules do not apply to existing vessels.

Mitigative Potential

Segregated ballast tanks will greatly assist in the reduction of pollution of the seas from operational activities, such as cleaning tanks, as well as from accidents of collisions, rammings, and groundings.

System Costs

The costs of segregated ballast tanks will vary greatly with the size of vessels and whether segregated ballast tanks are installed when the vessel is constructed or installed as a retrofit. In 1977 MarAd estimated the cost of installing segregated ballast tanks in a new vessel of 225,000 DWT to be 18 million dollars.

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- United States Department of Commerce. Maritime Administration. Tanker Pollution Abatement Report. Washington, D.C., July 1977.

CRUDE OIL WASHING (COW)

System Definition

Crude oil washing is a method of cleaning cargo tanks using crude oil as a solvent.

System Description

Crude oil washing uses the force and solvent action of crude sprayed against bulkheads, and bottom structure to remove sludge, waxes, tars and other sediments left after a tanker discharges cargo. Both the solvent and sludge are pumped out of the tanker together.

Inert gas is required to maintain an explosion free atmosphere in the tank. In lieu of an inert gas system Esso Petroleum Company Limited has experimented with an atmospheric concentration that is above the upper explosive limit for the crude vapor. This is considered, however, a more risky method and requires strict monitoring of the tank atmosphere. Lav-Jets powered by air driven Porta-Drivers or self-contained LAVOMATIC machines are the most commonly employed cleaning devices.

System Capability

- Can remove in the order of 90 percent of the sediment and rust in tanks.
- Reduces by about 30 percent the time needed for washing tanks.

System Advantages

- Provides a method to reduce amount of pollution in marine ballast.
- Reduces time of tank cleaning.
- Provides for effective increase in carrying capacity of VLCC by putting what would have been pumped overboard into the pipeline.
- Long term reduction of tank corrosion.

System Disadvantages

- Requires inerting system to make operation safe; i.e., prevent explosion.
- Still somewhat experimental.
- May be grade dependent in its performance.

Mitigative Potential

Crude oil washing plus an inert gas system can reduce marine pollution through ballast discharge plus give a fair guarantee of explosion safety.

System Costs

Highly variable depending on complexity of system.

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III. SURVEY CATEGORIES

C. Personnel

1. Vessel Manning
2. Personnel Training
3. Personnel Standards

VESSEL MANNING

System Definition

The Coast Guard is charged with responsibility for determining the minimum manning requirements necessary for the safe navigation of vessels which are issued a Certificate of Inspection. The authority for this determination has been issued to the Officer in Charge, Marine Inspection (OCMI).

System Description

The minimum number of licensed officers and crew members necessary for the safe navigation of the vessel are stated on the Certificate of Inspection. The OCMI is guided by various statutes and regulations including:

A. Division into three watches: 46 CRF 157.20-5, 46 U.S.C. 673.

B. Eight-hour day: 46 CFR 157.20-10, 46 U.S.C. 673.

C. Able seamen: 46 CFR 157.20-15, 46 U.S.C. 672.

D. Lifeboatmen: 46 CFR 157.20-20, 46 CFR 33.30, 46 CFR 78.14, 46 CFR 97.14.

E. Mates: 46 CFR 157.20-25, 46 U.S.C. 223.

F. Master: 46 CFR 157.20-30, 46 U.S.C.

G. Radar observers: 46 CFR 157.20-32.

H. Engineers: 46 CFR 157.20-35, 46 U.S.C. 404.

I. Pilots: 46 CFR 157.20-40, 46 U.S.C. 404, 46 U.S.C. 364.

J. Lookouts: 46 CFR 157.20-45.

K. Fire Patrolmen and Cabin Watchmen: 46 CFR 157.20-50, 46 CFR 78.30, 46 U.S.C. 470.

L. Radio Officers and Radiotelegraph Operators; watches: 46 CFR 157.20-50, 46 CFR 157.20-55, 46 U.S.C. 222, 229a.

M. Tankerman: 46 CFR 157.10-80, 46 CFR 31.15, 46 U.S.C. 391a.

N. Operators: 46 U.S.C. 390b, 46 CFR 157.30-7, 46 CFR 157.30-35, 46 CFR 186, 46 U.S.C. 405b, 46 CFR 157.30-45.

O. Staff Officers: 46 CFR 157.20-60, 46 U.S.C. 155, 46 U.S.C. 242.

P. Qualified members of the Engine Department: 46 U.S.C. 672 (e).

Q. Ordinary seamen: 46 CFR 157.20-15, 46 U.S.C. 672.

The Commandant has stated in the Marine Safety Manual (CG-495): "It is necessary that the OCMI who certificates the vessel consider the following in addition to the statutory and regulatory requirements:

A. Size of vessel,

B. Route,

C. Hull and equipment maintenance needs (protective coatings, cargo gear, equipment sophistication, etc.)

D. Maintenance of machinery and equipment,

E. Degree of automation of deck and engineer room equipment,

F. Type of cargo,

G. Cargo transfer system,

H. Successful operations of similar vessels,

I. Fire protection systems (crew operational requirements),

J. General arrangement of vessel equipment as it relates to the crew operational requirements,

K. Level of qualification of each crew member to perform tasks demanded by the vessel's mission,

L. Lifesaving equipment,

M. Spare parts allowance,

N. Number of passengers carried,

O. Hazard peculiar to route and service, and,

P. Hours of operation within a 24 hour period."

In an effort to provide a uniform application of the regulations and guidelines for manning, the Marine Safety Manual also provides sample manning scales for various classes of vessels. These samples are not mandatory but provide assistance in promoting uniformity. Illustrative of the samples provided is the following for cargo and tank vessels of 1,600 tons and up:

Ocean and Coastwise (Stream)

1 -- Master	1 -- Chief Engineer
1 -- Chief Mate	1 -- 1st Assistant Engineer
1 -- 2nd Mate	1 -- 2nd Assistant Engineer
1 -- 3rd Mate	1 -- 3rd Assistant Engineer
* 6 -- Able Seamen	* 3 -- Firemen/Watertenders
* 3 -- Ordinary Seamen	* 3 -- Oilers
1 -- Radio Operator	

* variables

The variables listed are stated as follows:

Able Seamen -- Depending on the size of vessel, amount of lifesaving equipment, and needs for safe navigation, this number may vary. At least 65 percent

of the deck crew must be Able Seamen (46 U.S.C. 672(a)). In general, however, 6 AB's are required (2 per watch) to provide for the lookout and helmsmen functions.

Ordinary Seamen -- This number will vary in proportion to the total deck crew on unautomated vessels. On vessels where automated control systems and laborsaving devices have been installed on deck to ease the work of the seamen, and provisions for mess and sanitary facilities and an effective call system have been included in the vessel's design, the requirements for ordinary seamen vary. Where it has been considered appropriate, the requirement for ordinary seamen has been replaced by a requirement for dayworking deck maintenance men. On some highly automated vessels with shoreside maintenance support, a requirement for an unlicensed deck department consisting of 6 AB's has been considered adequate. Unlicensed deck manning levels which are lower than the conventional 6 AB's and 3 ordinary seamen must be approved by the Commandant (G-MVP).

Firemen/Watertenders, Firemen and Oilers -- The number and qualifications will vary based on the number of boilers, type of fuel, number of furnaces, location of boilers, arrangement of machinery spaces, and type and amount of automation. In the case of diesel vessels, no firemen/watertenders are normally required.

Mitigative Potential

As vessels become larger and more sophisticated, the need of properly trained crews becomes more apparent. Coast Guard manning requirements encompass not only the safe navigation of these vessels but also consider the maintenance, working conditions and type of cargo carried. Strict adherence to the regulations and policies should have a beneficial mitigating effect on vessel casualties.

IMCO is scheduling a conference on vessel manning with the thought of producing an international convention on the subject. If such a convention is approved by IMCO and ratified by member countries, it should have a beneficial impact on the potential for reducing vessel casualties.

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PERSONNEL TRAINING

System Description

The United States Coast Guard is not involved in the actual training of merchant marine officers and seamen. However, merchant marine training is available throughout the country. The United States Merchant Marine Academy and the several state Maritime Academies conduct four-year courses qualifying graduates to take the Third Mate and/or Third Assistant Engineer examination for ocean and coastwise steam and motor vessels. Completion of these courses qualifies deck officer graduates for certificates as Radar Observers and all graduates for endorsements as Lifeboatmen on their Merchant Marine's Document (MMD).

In addition to the United States Merchant Marine Academy, the Maritime Administration also has Radar Observer Schools in Radar Training Centers in five places around the country.

Maritime labor unions also conduct schools for their members. As there are various labor unions for deck officers, engineer officers, radar officers, seamen and firemen, training is widespread and comprehensive. These schools train people for original officers licenses and upgrading of licenses and for the many endorsements of the seamen's MMD's.

Many marine companies have training for officers and seamen employed by their organizations. These would normally be tailored to a special type vessel or unusual cargo handled by that particular company.

The United States Coast Guard will not accept any certificate of training or successful completion of a course in lieu of its examination or qualification requirements until it has studied and approved the curriculum and teaching methods for the training course. This assures the high quality of Coast Guard examination and qualification requirements for all officers and seamen are maintained.

The Coast Guard requires special training for certain jobs on vessels carrying hazardous cargo, such as LNG.

Mitigative Potential

It has been stated that vessels crews are a contributing factor in 80 to 85 percent of tanker casualties. IMCO, at United States initiative, held an International Conference on the Convention on Training and Certification of Seamen in London in June 1978. As of this writing, the report of the conference is not available.

The Coast Guard is considering simulator training as a requirement for Masters and Chief Mates serving on very large vessels. MarAd has been tasked to

determine what simulator training could be substituted for shipboard experience. The subject of simulator training was considered at the time of the June 1978 conference.

There is every reason to believe establishment of international standards for crew training and certification will have a beneficial impact on the potential for reducing vessel casualties.

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PERSONNEL STANDARDS

System Definition

Part of the Commercial Vessel Safety Program is the development of personnel standards. These standards are to ensure that personnel, both licensed and unlicensed, operating the vessels possess the requisite skills, knowledge, and physical attributes required to safely and adequately perform these duties.

System Description

The U.S. Coast Guard issues some 52 different categories of licenses for officers and operators of licensed and unlicensed vessels of the United States. These categories may be further broken down by limitation of vessel size, type and horsepower. An applicant for any license issued by the Coast Guard must satisfy citizenship, physical examination, character and service requirements before being permitted to take the examination requested.

By the time an applicant has been issued a license as Master of Ocean and Coastwise Steam or Motor Vessels, he will have been examined in some 33 different subjects. Most subjects are repeated from prior examinations for lesser license but the questions become more difficult with succeeding examinations. The subjects cover all aspects of merchant vessel operations including navigation, rules of the road, seamanship, lifesaving, fire fighting, pollution and laws governing marine inspection.

A Chief Engineer of Steam or Motor Vessels will cover some 75 subjects prior to attaining that license. The subjects will include propulsion machinery, boilers, electricity, refrigeration, engineering, safety and general operation and repair.

License examinations have undergone considerable change since they were instituted in 1852. Until recently most licenses were of an essay type requiring a week or more to complete. Additionally, there were problems in maintaining the approximately 5,000 to 7,000 questions up-to-date due to the rapid changes in vessel size, type, equipment, machinery and cargoes carried. There has also been a problem in standardizing the types of questions given and in marking the essay type answers.

For many years the Coast Guard has been studying and experimenting with multiple choice type questions. This type of examination is not only less time consuming, but is capable of being modernized much more readily. The marking of

examinations has been standardized by the simple expedient of having all examinations given throughout the United States scored by a single group at the United States Coast Guard Institute of Oklahoma City. At this time all examinations for licenses for deck and engineer officers on ocean and coastwise vessels are multiple choice type examinations. Additional time will be required to change other categories of licenses to this type of examination.

In addition to officer's licenses, all seamen sailing on board certificated vessels require Merchant Mariner's Documents (MMD). Each MMD is endorsed by the Coast Guard to indicate the type of employment for which the holder has been certified.

Each applicant for an original MMD must provide acceptable evidence of citizenship and satisfactory proof he has a commitment for employment. An alternative to proof of employment is a transcript of prior military sea service.

Original MMD's are endorsed as "Ordinary Seamen," "Wiper" and/or "Steward's Department". The original MMD can be endorsed "Steward's Department (FH)" for employment as a food handler if he provides satisfactory proof of a physical examination stating he has no communicable disease.

Subsequent endorsements on the MMD for more senior employment in the deck or engine departments require proof of stipulated lengths of sea service and the successful completion of an examination for the required rating.

Mitigative Potential

Due to the universal understanding that most vessel casualties are caused by human error, much worldwide attention is being given to the qualifications of persons employed on merchant vessels. This subject is presently being discussed in meetings of the Intergovernmental Maritime Consultative Organization (IMCO), a specialized agency of the United Nations. It is hoped that an agreed minimum standard for personnel qualifications and training will result from these meetings. It is recognized the United States has the most vigorous requirements and the Coast Guard is using them as a basis for their discussions in IMCO.

The use of foreign flag vessels and foreign crews in United States waters is continually increasing. An article in July 1978 issue of the National Geographic states: "Economy often dictates the nationality of tanker crews as well, and the registry of the ship itself. By law, American flag ships must carry American crews, whose wages reflect their country's standard of living. An Italian captain may earn $20,000 a year, an American captain, $60,000." It goes on to state the cost of an

American crew is about $1.8 million per year, an Italian crew about $800,000 and a Filipino crew about $400,000 per year.

With these economics driving more owners to foreign crews, it is incumbent on the United States to obtain the highest possible personnel standards in an international convention agreed to by IMCO members.

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III. SURVEY CATEGORIES

D. Other

1. Celestial Navigation
2. Enforcement

CELESTIAL NAVIGATION

System Definition

Celestial Navigation is the practice and methodology of navigation using as aids the sun, moon, planets and the major stars as listed in the Nautical Almanac. Lines of position are computed by solutions to celestial triangles, using spherical trigonometry and graphical plotting.

System Description

Two systems of coordinates are used in determining position by celestial navigation. The first is the system of coordinates on the celestial sphere, the infinite sphere on the surface of which all stars lie. Sun, moon, planets also are assumed to lie on the sphere but must be corrected for parallax. The second is the system of coordinates based on the position of the observer and is called the horizon system of coordinates. The reference plane here is the observer's celestial horizon, whereas in the celestial sphere the reference plane is the celestial equator or equinoctial. The celestial horizon is the plane that passes through the center of the earth and is normal to a line drawn from the observer to the center of the earth. Extension of this line forms the zenith and radiates at the points of intersection with the celestial sphere. The celestial horizon is parallel to the plane of the observer's visible horizon at sea, which is equivalent to the sea horizon. All celestial body altitudes are referred to the latter, and are measured along a great circle touching the zenith, nadir, and celestial body being measured for altitude.

The results from the measurement of altitude by sextant of a celestial body, and the Greenwich hour angle (GHA), a celestial triangle whose vertices are the celestial pole, zenith, and position of celestial body. The lengths of the sides are respectively 90° -altitude, 90° -declination, and 90° -latitude of observer's meridian. The respective angles corresponding to these sides as the so called t or meridian angle or (LHA), azimuth angle, and a third angle opposite 90° -latitude, the parallactic angle, which is not used in celestial navigation.

The projection of the celestial triangle onto the surface of the earth results in the navigational triangle with the three vertices: geometric position of celestial body (GP), position of observer M, and the nearest or elevated pole either north or south depending on the hemisphere the observer is in. The sides are respectively the co-altitude, co-latitude and polar distance.

The fundamental problem for the navigator is to determine the GP of a celestial body by means of an altitude measurement with a sextant and an GHA

determination via time and the Nautical Almanac. This establishes the observer's position somewhere on a circle of radius equal to the co-altitude. Since the azimuthal accuracy is not sufficient to fix the observer's position point on the circle of equal altitude, at least one other sight is needed. (Some advanced navigational observing instruments can indeed measure azimuth sufficiently to determine position from one star. GEON is an example.) Knowing the approximate position (AP), the time of sighting, and the GP of the respective star, LHA, polar distance, and co-latitude can be calculated and plotted; i.e., two sides and an included angle, t, of a spherical triangle are known and the rest solved for. This yields a computed side opposite, t, or the co-altitude. There is also the observed co-altitude. The difference between the two is known as the altitude intercept and represents the difference between the length of the radii of the computed and observed circles of equal altitude. This difference, a, is extended along the azimuth of GP to or from the assumed position, AP, depending on whether the computed altitude is greater than or less than the observed altitude. Azimuth of GP is a computed value.

At right angles to the difference, a, along the azimuth of GP a line of position, LOP, representing a small part of the circle of equal altitudes is drawn. This process is repeated for several celestial bodies and the intersection of these respective LOP's is noted. This intersection represent the ship's position. If no AP were available, the triangle intersection of three circles of equal altitudes from three star sights would determine position uniquely.

System Capability

Celestial navigation is the oldest method of determining position once out of sight of land. Provided one has the ability to sight two or three separated celestial bodies and accurate time keeping is available, system accuracy is high.

System Accuracy

Celestial navigation using a marine sextant is as accurate as the personal skill of the navigator. A steady hand, good horizon, steady deck, sharp pointed plotting pencil and accurate chronometer all help. Automated accurate sight, tracking methods aid materially in increasing accuracy.

System Advantages

- Celestial navigation is a reliable system.
- Celestial navigation is easy to learn for anyone with a high school background. It becomes essentially a table lookup method.

- Requires relatively inexpensive and reliable accessories: charts, tables, sextants, chronometers.

System Disadvantages

- Requires clear weather and a good horizon for sights.

Mitigative Potential

Celestial navigation coupled with powerful star tracking methods for taking star sights is a reliable backup method for determining position. It does not, however, have the potential for high accuracy position determination, such as differential Omega.

System Costs

The cost of this system is very low.

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ENFORCEMENT

System Definition

The Office of Merchant Marine Safety administers the Commercial Vessel Safety Program of the Coast Guard. The objective of the Commercial Vessel Safety Program is to minimize loss of life, injuries and property damage involving commercial vessels of the United States.

System Description

The development and enforcement of standards for domestic vessels covers several efforts. One of these is the development of materiel standards for vessels and equipment. These standards are developed from experience gained in the field and an analysis of casualties in conjunction with an input from industry and scientific and professional bodies such as the American Institute of Merchant Shipping, the American Petroleum Institute, the Society of Naval Architects and Marine Engineers, and the National Academy of Sciences. These standards, when developed, are applied to commercial vessels from their inception until their final removal from the list of merchant vessels of the United States. The first step in the application and enforcement of standards is plan review by personnel assigned to the Merchant Marine Technical Division. Plans for vessels whose construction is anticipated are submitted by the naval architects or the prospective owners for review and approval prior to commencement of construction. The personnel assigned to plan review are both officers and civilian personnel. The officers assigned are predominantly those that have completed post-graduate training in the fields of naval architecture or marine engineering. There are six geographical locations where plan review is performed. The review, which involves new designs or concepts or new and unusual operating characteristics, is conducted at Headquarters by the Merchant Marine Technical Division. Designs of vessels of a more conventional nature are reviewed in five field technical offices located in New York, Portsmouth, Cleveland, New Orleans, and San Francisco.

The next phase of the enforcement of standards is performed by personnel from the field marine safety and marine inspection offices. This consists of the inspection of the vessel during its entire period of construction to ensure that the vessel is constructed in accordance with the approved plans and built in accordance with good engineering practice. Upon completion and outfitting, the vessel is issued an original certificate of inspection certifying to its construction in accordance with

the standards and indicating the manning and equipment required. Throughout the remainder of the life of the vessel it will be subjected to periodic inspections to verify that the standards are maintained and the equipment onboard is in proper operating conditon to ensure safety of life and property at sea. These inspections are carried out by personnel in the 48 marine safety and marine inspection offices located in the continental United States as well as in Alaska, Hawaii, Guam and Rotterdam.

Mitigative Potential

The United States Coast Guard's enforcement of regulations in its vessel safety program is recognized as one of the best in the world. Yet serious accidents do occur in United States waters involving both foreign and domestic vessels. Title II of the Ports and Waterways Safety Act of 1972 states that existing standards "must be improved for the adequate protection of the marine environment." Not only must existing standards be improved but also the enforcement procedures must be increased to recognize the level of safety and environmental protection desired.

As there are many more foreign flag vessels entering the United States waters than domestic vessels, international standards must also be upgraded and enforced. The United States Coast Guard is heavily involved in the Intergovernmental Maritime Consultative Organization (IMCO) to accomplish this need. The United States is being successful in its deliberations in IMCO in obtaining stronger international safety and environmental protection standards along with the required enforcement standards.

The tanker boarding program to board all foreign tankers entering United States ports to determine compliance with all applicable safety and pollution standards under both domestic regulations and international agreements appears to be an effective mitigative measure. International standards for certification of vessels calling for more strict provisions for regular surveys and unscheduled inspections are being discussed in IMCO to increase the safety and pollution standards of all vessels.

It has been stated that "Better training and stricter enforcement of regulations, not equipment changes, is the answer to most of our problems."

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IV. TECHNOLOGY/SERVICE ALTERNATIVES

The purpose of this subsection is to discuss Technology/Service Alternatives in the context of current practice within the merchant fleet (VLCC's in particular) as compared to the new requirements imposed by the Ports and Waterways Safety Act of 1972 as amended by the Port and Tanker Safety Act of 1978 and the Deepwater Ports Act of 1974. Further, to address alternative systems or equipments which are, or will be, available to supplement the new baseline system required by these laws to be carried by 1985 (i.e., Loran-C and Dual Radars). These systems and available alternatives are illustrated in figure 4.

Current practice in the 1979 timeframe can be described as the onboard systems, carried as a minimum suit, which will provide for the safe navigation of a vessel. This does not imply that all maritime companies provide only this basic suit, since some are willing to equip their ships with more sophisticated systems if they are deemed to be cost effective for that particular application.

Certain fundamental equipments are in common usage:

A. Ship Control

1. <u>Navigational Aids</u>

a. <u>Electronic Navigational Aids</u>

Position fixing by electronic means is the most common practice at sea today. Various systems are in use worldwide; however, in the off-shore waters of the United States, Loran A was the most common, but is being replaced by the more advanced Loran-C system. This latter system is a principal feature of the Baseline System in the 1985 timeframe. Loran-C affords an order of magnitude improvement in accuracy over Loran A, is relatively inexpensive, and provides good coverage in the Deep Water Port region of the Gulf of Mexico.

Alternative systems are now state-of-the-art such as Decca and Omega; however, the former does not provide coverage in the Gulf, while the latter is not sufficiently accurate for near-shore navigation. The cost of shipboard equipment to use these systems is compatible with Loran-C. Other alternatives such as Consol and Consolan are not considered viable alternatives, owing to insufficient accuracy for DWP application. Satellite navigation is limited in availability, since more satellites are needed to provide continuous coverage. Inertial systems are considered to be too expensive for merchant marine usage. Other military systems are not considered viable in the VLCC context, owing to security classification and/or cost.

Figure 4. Technology/Service Alternatives

Technical Factors	Current Practice[a/]	Available Alternatives
A. Ship Control		
1. Navigational Aids		
a. Electronic Navigational Aids	Loran-C Dual Radar Fathometer RDF/ADF Bridge-Bridge R/T Ship-Shore Radio Radar Beacon Marine Info Bcsts Tech Svc Bcst	Decca, NAVSTAR, NAVDAC, Omega, SINS, MINDAC, NAVSAT. Doppler Nav Collision Avoidance Systems Sonar
b. Mechanical Navigational Aids	Autopilot Pitometer Log Gyro Compass	Rate-of-turn indicator Dead Reckoning Analyzer
c. Visual and Audible Aids to Navigation	Buoys Lights Fog Signals	RACON, RAMARK
2. Weather Aids	Weather Broadcasts	
3. Maneuvering Aids	Auxiliary Steering	Bow Thrusters Bottom Clearance
4. Advisory Procedures	Traffic Separation Scheme[b/]	Vessel Traffic Services
B. Pollution Control	Segregated Ballast Flue Gas Inerting System Crude Oil Washing	Double Bottom Double Hull
C. Personnel	Manning Training Standards	
D. Other	Celestial Enforcement	Radio Sextant

a/ Updated to Baseline System in 1985 (Loran C and dual radars).
b/ Limited applications (Puget Sound, Nantucket, etc.)

Radars in the 3 cm band are commonly found at sea today. Since many casualties have been attributed to malfunctioning shipboard radars, the new 1985 baseline suit requires dual radar systems onboard for redundancy rather than improved reliability of any particular radar system.

All collision avoidance systems use primary inputs of radar range and bearing to surface targets, and show promise of reducing casualties by warning watch officers of impending dangerous situations. In some systems, the watch officer may test possible maneuvers to determine if in fact they will avoid danger given, of course, that the course and speed of the target remain unchanged.

Echo sounding fathometers are, in general, used to indicate under-keel depth. In deep water, accuracy is somewhat degraded since the return echo indicates the shallowest point of the cone of sound on the bottom. Further, owing to the time required to transmit a pulse and receive an echo, the fathometer indicates depth at some point astern of the transducer when the ship has way on. Fathometers can be equipped with alarms to warn watch officers of some pre-set threshold of depth; however, this application to the VLCC is marginal when one considers the poor maneuverability of the VLCC in an emergency situation. Sonar systems might supplement the echo sounder, since they could be steered ahead of the ship to sense rapid shoaling or obstructions; again the maneuvering ability of the VLCC is a factor.

Direction finding, manual or automatic, while relatively inexpensive and in use worldwide does not offer sufficient accuracy to benefit VLCC's.

Radio communications among ships and to stations ashore are vital for the relay of information concerning maneuvering intentions, weather, logistics, search and rescue, etc. Redundancy, as in the case of radar, appears to be a promising alternative to ensure availability.

Aids to navigation such as radar beacons and routine radio broadcasts are now available and useful. No alternatives are apparent; however, in any electronics application greater reliability and freedom from atmospheric or other electronic interference is desirable.

b. Mechanical Navigational Aids

Most merchant ships today are equipped with a means of automated steering whereby rudder orders are generated by a simple servo system driven by gyro input. Such systems maintain set course more accurately than manual steering and reduce fuel consumption.

On VLCCs the rate-of-turn is an important factor to the pilot/watch officer when maneuvering in a channel or other confined area. Rate of turn indicators are in common use, and can be displayed on the bridge for ships so equipped.

Gyro compasses are part of the basic navigation suit among merchant ships as are various types of pitometer logs. Course and speed thus obtained are combined to perform dead reckoning of position by the navigator. An alternative system is the Dead Reckoning Analyzer (DRA) which automatically computes an estimated position from gyro and pitlog inputs; however, current and wind effects are omitted. The DRA is an important adjunct to navigation when electronic or visual aids are unavailable due to weather, interference, etc.

c. Visual and Audible Aids to Navigation

Buoys, lights, and fog signals are currently in existence universally, although standards may vary from one jurisdiction to another. Visual aids may be obscured by fog, poor visibility or height of eye; however, they may be enhanced by the alternative means of radar beacons (RACON) and radar markers (RAMARK). These systems provide information independent of weather.

2. Weather Aids

Various weather broadcasts provide current conditions and forecasts to mariners. There appear to be no alternative systems at this time.

3. Maneuvering Aids

As a general rule, all large ships have some emergency means of steering by manual movement of the rudder. In its most elementary form, chain-falls can be rigged to the rudder, allowing the rudder to be moved, albeit slowly.

Alternatives comprise auxiliary steering systems, which are electro-hydraulic and may or may not be fully independent of the primary steering system. Legislation now requires that two fully independent steering systems be carried by all ships over 10,000 gross tons.

Better steering control at low speeds can be provided by bow thrusters, which are especially helpful when docking and undocking.

Requirements for minimum bottom clearance exist for certain ports and channels where the "squat" or roll of a ship with way on may be sufficient for it to touch bottom and/or ground.

4. Advisory Procedures

Traffic Separation Schemes are in use in certain areas of the world for the purpose of reducing the risks of casualties. These include two-way routes, tracks,

areas to be avoided, etc. Compliance with these schemes is generally voluntary on the part of the master, and where jurisdictions overlap are very slow to materialize.

Alternatively, Vessel Traffic Services offer a positive means of controlling ship movements in high risk areas having congested traffic and poor visibility. A typical vessel traffic service is comprised of one or more of the following subsystems: Traffic Separation, Vessel Movement Reporting, Basic Surveillance, Advanced Surveillance, and Automated Surveillance. Control may be passive, advisory, or active depending upon the nature of the system. It would appear that the greatest payoff in risk reduction would lie in an active system, although the investment in personnel and equipment would be high.

B. Pollution Control

Since the VLCC is a relatively recent phenomenon, it is believed that the majority of these ships are, or will be equipped with:

Flue Gas Inerting Systems to reduce the risk of explosion in cargo tanks, segregated ballast tanks to reduce likelihood of pollution by dumping contaminated ballast, and Crude Oil Washing Systems which reduce the amount of pollution in marine ballast.

Alternative systems to supplement the foregoing include double bottoms, which reduce the risk of hull puncture on grounding, and double hulls which would also afford risk reduction in collisions. Both systems increase construction costs significantly while reducing stability (where flooded) and cargo capacity and do not seem to be applicable to backfitting on existing VLCCs.

C. Personnel

United States regulations regarding manning, training and personnel qualification standards are precise, while those of other nations are generally less demanding. Consequently, it is difficult to assess the overall quality of personnel among various national merchant fleets.

International agreements are well advanced in these areas, which should tend to standardize personnel qualifications and upgrade the world VLCC fleet.

D. Other

Celestial navigation has largely been replaced by electronic navigation systems at sea today, but remains as the most dependable method under a variety of conditions. However, celestial navigation cannot be used in poor weather.

The radio sextant is a passive, all weather system which overcomes the shortcomings of conventional celestial navigation, but is expensive and difficult to maintain.

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